TAMPERE UNIVERSITY OF TECHNOLOGY
TAMPEREEN TEKNILLINEN YLIOPISTO

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CLASSIFICATION OF COST DATA AND ITS USE IN 5D BUILDING INFORMATION MODELLING

Master of Science thesis

Examiner: prof. Kalle Kähkönen
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ABSTRACT

LOTTA HAKANEN: Classification of Cost data and its use in 5D Building Information Modelling
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The purpose of this research was to evaluate the possibilities of a construction company’s cost data classification. The case company’s cost data became inaccurate when proceeding from cost estimation to execution and the objective was to gather comparable data from projects. The cost data was examined with 5D BIM application iTWO, which was studied in this research.

The research consists of a literature review and a case study. The implementation of 5D BIM application was studied and essential cost management decisions were documented during the research. The case study demonstrated the usage of 5D BIM application. This was limited by using an example of light partition walls and the puttying and painting of them in an ongoing project.

It could be conducted that the used 5D BIM application enables controlling of cost data by low hierarchy level from the beginning of the project to the end. The most important part of cost data management is the controlling structure, which is used for reports and comparing projects. The usage of the application was good and it was considered as a reliable source of information. Collaboration between project participants is needed to use 5D BIM application in the most efficient way. The same data is used throughout the project, so sequential phases should be taken into consideration when creating new information or structuring it. Most of the essential information of the project can be found in the building information model, which means that the designers must have clear instructions about the use of information fields or additional application should be used for standardization.

TIIVISTELMÄ

LOTTA HAKANEN: Kustannustiedon luokittelu ja käyttö 5D tietomallinnuksessa
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Avainsanat: 5D-tietomalli, rakentamisen kustannushallinta, taloudelliset analyysit, kustannustieto, luokittelujärjestelmät

Tämän tutkimuksen tavoitteena oli selvittää rakennusalan yrityksen kustannustiedon luokittelujärjestelmän mahdollisuuksia taloudellisiin analyyseihin. Kohdeyrityksen ongelmana oli kustannustiedon tarkkuuden heikentyminen projektin edetessä laskennasta tuotantoon. Tavoitteena oli saada projekteista vertailukelpoista tietoa. Kustannustietoa lähdettiin tarkastelemaan uuden tietomallipohjaisen 5D-ohjelmiston, iTWO:n, kautta. Yhtenä tutkimuksen tavoitteista oli testata tätä 5D-tietomalliohjelmaa ja sen mahdollisuuksia.

Tutkimus koostuu kirjallisuuskatsauksen lisäksi tapaustutkimuksesta. Tapaustutkimuksen kehitysprojektissa seurattiin 5D-tietomalliohjelman käyttöönottoa kohdeyrityksessä ja dokumentoitiin kustannusten hallinnan kannalta oleellisia päätöksiä. Demonstraatiossa testattiin 5D-tietomalliohjelman käyttöä valitulla luokittelujärjestelmällä käyttäen esimerkkinä kevyitä väliseinätöitä sekä niiden tasoitusta ja maalausta käynnissä olevassa projektissa.

Työssä saatiin selville, että käytetty 5D-tietomalliohjelma mahdollistaa kustannustiedon seurannan hyvin tarkalla tasolla projektin alusta loppuun asti. Kustannustiedon luokittelun kannalta tärkein osa on seurantarakenne, jota käytetään raportointiin ja projektien väliseen vertailuun. Ohjelman käytettävyys oli hyvä ja se toimi luotettavana tiedonlähteenä. Yhteistyötä projektin osapuolien välillä pitäisi parantaa, jotta 5D-tietomallinnusta voitaisiin hyödyntää tehokkaasti. Ohjelma käyttää luotuja tietoja läpi projektin, joten epätarkkuus aiemmassa työvaiheessa saattaa aiheuttaa ongelmia seuraavissa. Suuri osa projektin toteutuksen kannalta oleellisista tiedoista löytyy tietomalleista, joten niiden suunnitteluun on annettava tarkat ohjeet tai käytettävä muita ohjelmia tietomallin tietokenttien oikeellisuuden varmistamiseksi.

PREFACE

I began to write this thesis in Fall 2016. After a set of meetings with the case company Fira, the practical limitations had been established and I was able to begin my research. And even though I have felt from time to time that I'm not really sure what I'm doing, it all have cleared out to me throughout this process.

It has been a privilege to write my thesis about 5D BIM and to have the opportunity to be certified in the use of the application used in this research. The implementation project team have treated me well and I feel grateful to all of them. I would especially like to thank my instructors Mikko Mäläskä and Aleksi Juusela from Fira, for the comments and guidance they gave. I would also like to thank Professor Kalle Kähkönen for his valuable comments and insights.

There are several people who have made my life as great as it is today. Special thanks to my parents, who have always supported me and trusted me. I would also like to thank my dear brother, in whose footsteps I entered the Tampere University of Technology. Spending over 5 years in TUT have been the greatest time of my life and I couldn't have made it through without Elina and Karo. My deepest thanks to my partner Simo, who has supported me and stood by my side believing in me, even if I didn't.

"The Road goes ever on and on
Down from the door where it began.
Now far ahead the Road has gone,
And I must follow, if I can,
Pursuing it with eager feet,
Until it joins some larger way
Where many paths and errands meet.
And whither then? I cannot say."

— J. R.R. Tolkien

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

BIM	Building Information Modeling, “*a modeling technology and associated set of processes to produce, communicate, and analyze building models”* (Eastman et al. 2011)
4D BIM	3D building information model with time dimension
5D BIM	4D building information model with cost dimension
Benchmarking	Comparing business’ processes or performance to the best in industry or internally
EVM	Earned Value Management
PBS	Product Breakdown System
WBS	Work Breakdown System
IFC	Industry Foundation Class, “*an open and standardized data model intended to enable interoperability between building information modeling software applications in the AEC/FM industry*” (Laakso & Kiviniemi 2012)
VDC	Virtual Design and Construction
iTWO	5D BIM application by RIB Software AB

1. INTRODUCTION

Building information modelling (BIM) has become increasingly common in the AEC industry. A survey in Finland showed that 92 % of the participants thought that they will be using BIM by 2018 and 90 % thought that they will be using BIM by 2016. (Finne et al. 2013) 3D BIM has developed to 4D, 5D, and even to 6D BIM. (Smith 2014) 4D links a time dimension to 3D objects, making it visual to present schedules and activities. 5D links cost data to this information, making it possible to present cash flows and cost of adjusted quantities, to mention a few. 6D is the dimension for as-built model for facilitation. This thesis concentrates on the 5D BIM and its possibilities for financial analyses.

The three main themes of this thesis are classification of cost data, information management and 5D BIM. With such classification systems, cost data can be stored and used for various informative reports. This information can be used to help decision-making for construction projects and with 5D the data behind these reports and the reports themselves are integrated into the building model.

1.1 Background and motivation

The case company Fira Oy was founded in 2002. Fira's three core values are caring, building together and virtual construction. (Fira Oy 2016a) The Next Phase – program began at Fira in 2015. This phase is focused on coming closer to people. Fira's vision of "People building smarter society together" is divided into three areas of development (Fira Oy 2015):

1. Smarter construction: reliable turnaround from end to end
2. Smarter jobs: most desirable innovative building trade community
3. Smarter business: culture of creation, piloting and growth

This study is based on areas one and three. To create reliable turnaround, you need to be able to make decisions based on information and have the possibility to compare similar projects to each other. Smarter business enables, for example, development through digitalization. The case company has set three goals for the development project:

1. E2E-synchronisation from BIM to cost calculation
2. Forecast for committed cost
3. Single source of truth for money

These goals are supposed to be reached with RIB Software AG's application iTWO, which combines traditional planning with 5D planning. (RIB Software AG 2016b) This thesis is a part of this development project.

1.2 Research objectives and methods

The case company has identified a set of main problems with the current cost data model. Those problems are presented in Figure 1. The cost data model in the case company is based on the Finnish Talo 80 classification. This classification is used for cost estimates and cost control on-site.

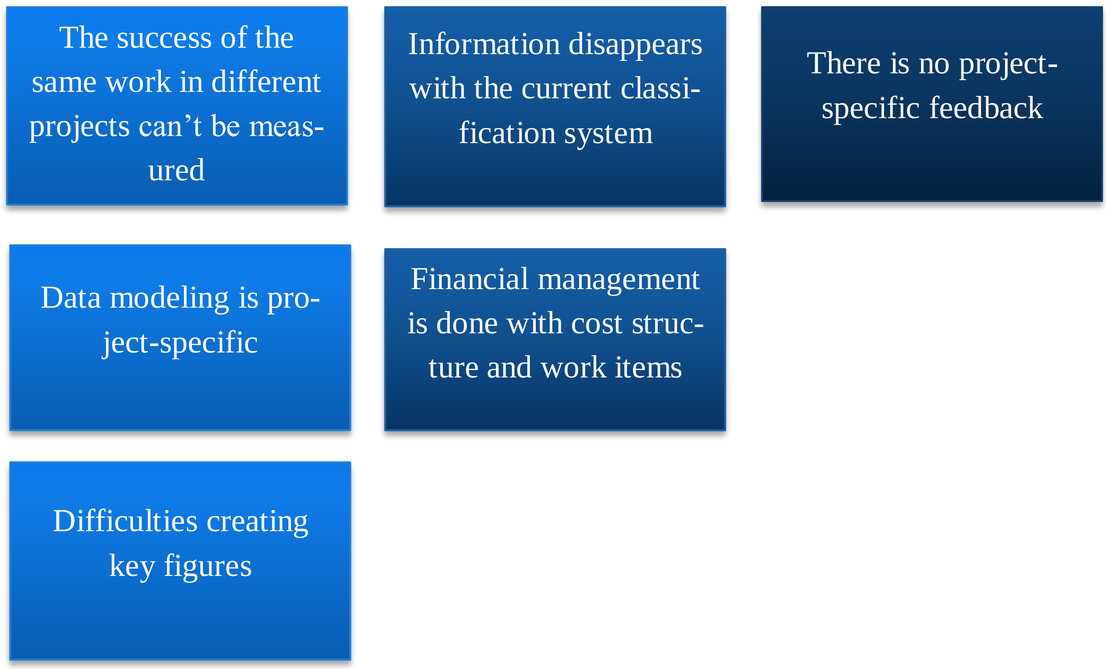

Figure 1. *The case company's problem regarding the presently used cost data model.*

The present cost data model is not capable of comparing different projects. The projects have the same core structure, but the content of the sublevels differs and is not standardized. There are also problems with learning from the projects, because information about the project's success in different areas is not communicated to parties working in the early stages. 5D BIM application will be used in the future, but it has not been tested enough yet. These problems result in the research questions presented in figure 2.

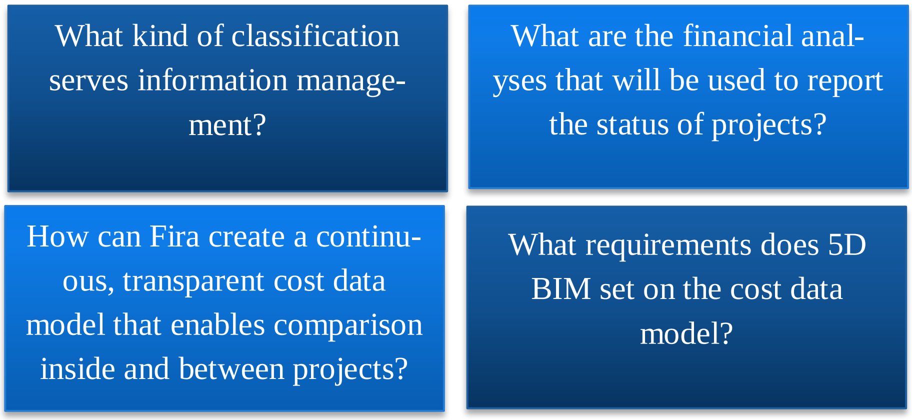

Figure 2. *Research questions.*

The objective of this thesis is to test the classification system used within a certain 5D BIM application. The systems should enable comparison within a project and between projects. This classification is used in iTWO, which is also the object of the research. The research objectives and methods are shown in Figure 3.

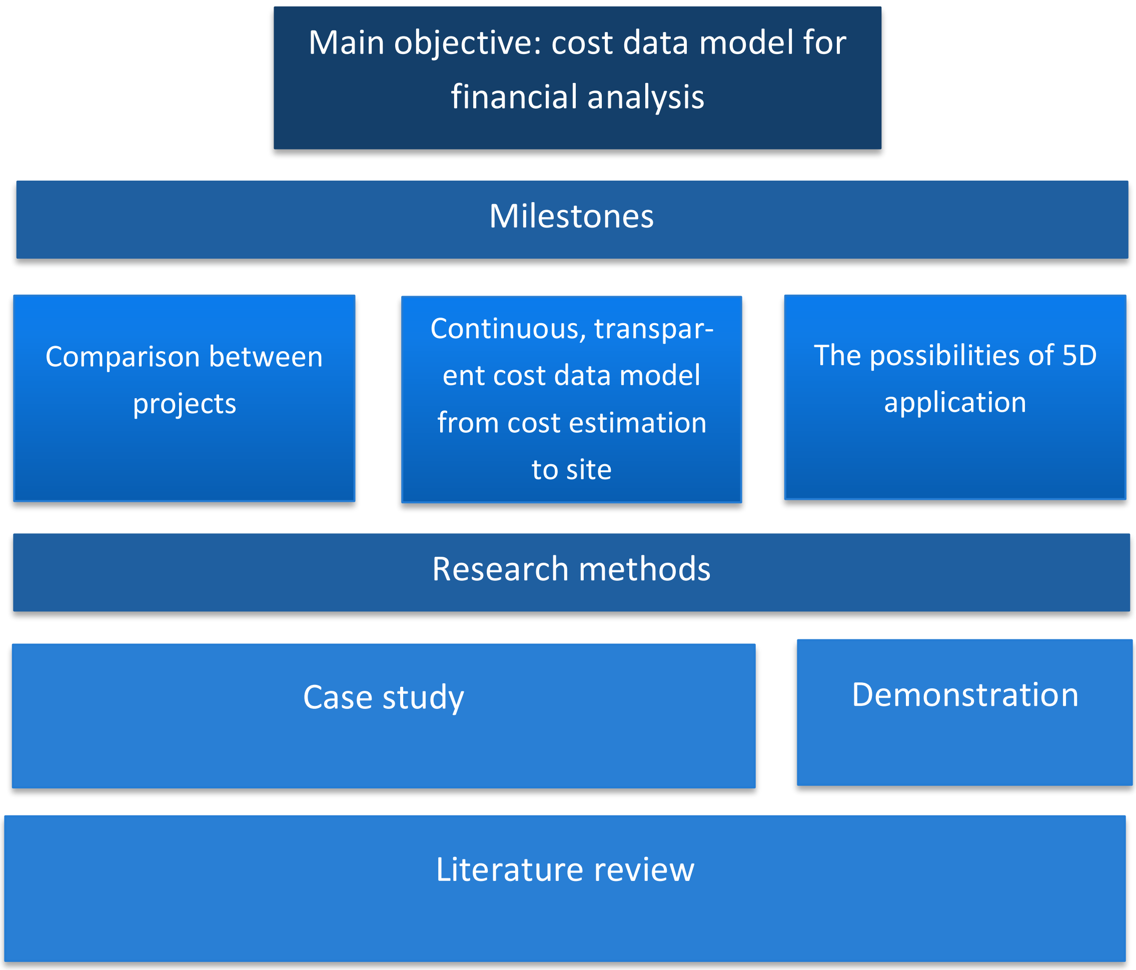

Figure 3. *Research objectives and methods.*

The possibilities and barriers of 5D BIM are researched in the literature review. The intention is to find out how data is modeled in construction projects, how information flows and what are the financial analyses used to measure the status of projects. This study is focused on residential turnkey projects, where the contractor is responsible for the design and furnishing (Gorse et al. 2012).

1.3 Practical limits

This report concentrates on the costs of building projects from the perspective of a contracting company. The scope starts with a feasibility study and ends in a guarantee period, creating an end to end process. Cost estimates, cost controlling and financial analyses are studied. The history of building information modelling is briefly described, but the focus is in 5D BIM. MEP systems are not included in this report.

The use of only one 5D BIM application and one case limits the empirical research. This study is heavily concentrated on the iTWO application and its use in cost management. The case study performed in the application is limited by using a small example of work: light partition walls. The demonstration concentrates on the execution phase.

1.4 The structure of this report

This report is divided into 7 chapters. The first chapter explains the background of this thesis and the objectives. The research questions and methods are briefly presented, as well as practical limits.

The literature review is presented in the second and third chapters. The second chapter explains cost management in construction and the different means for carrying out cost controlling and financial management. The third chapter examines the development of building information modelling (BIM) and the benefits and barriers of implementing 5D BIM. A set of 5D BIM applications are presented briefly.

The fourth chapter explains the empirical methods used in the report and introduces the case company. In the fifth chapter these empirical methods are used for collecting and presenting data. This data is reported and analyzed in chapter six.

In the final chapter a conclusion is made based on the research material. Further research areas are suggested.

2. CONSTRUCTION COST MANAGEMENT

Construction companies usually have considerable high revenue but profit margins can remain slim, particularly concerning competitive contracting. The Table 1 lists the largest Finnish building companies. The information is based on Balance Consulting's list of the largest Finnish building construction companies presented in the Kauppalehti newspaper.

Table 1. *Revenue and net profit of five largest Finnish building construction.* (Balance Consulting 2015)

Company	**Revenue milj. €**	**Net profit milj. €**	**Net profit %**
1. YIT Rakennus Oy	1143,7	31,4	2,75
2. Skanska Talon-rakennus Oy	728,7	23,6	3,24
3. NCC Rakennus Oy	708,3	20,0	2,82
4. SRV Rakennus Oy	613,0	19,3	3,15
5. Lemminkäinen Talo Oy	534,3	1,8	0,34
…			
12. Fira Oy (case company)	98,1	3,8	3,87

It can be seen from Table 1 that the net profit percentage of five largest companies is between 0,34 % and 3,24 %. This suggests that construction companies have high cash flow, but low profits.

This chapter explains how costs are created during a construction project and how they can be controlled. Different cost structures are examined and evaluated for their use in creating financial figures.

2.1 Formation of construction costs

A Finnish building construction project can be divided into seven phases (RT 10-11226 2016):

1. Feasibility Study
2. Concept Design
3. Design of Alternatives
4. Early Design
5. Detailed Design
6. Execution
7. Guarantee Period

As is seen in Figure 4, costs are determined in an early phase of project and slowly cumulate until execution starts. During the execution stage cost cumulation is faster, as actual construction starts and designs turns into reality.

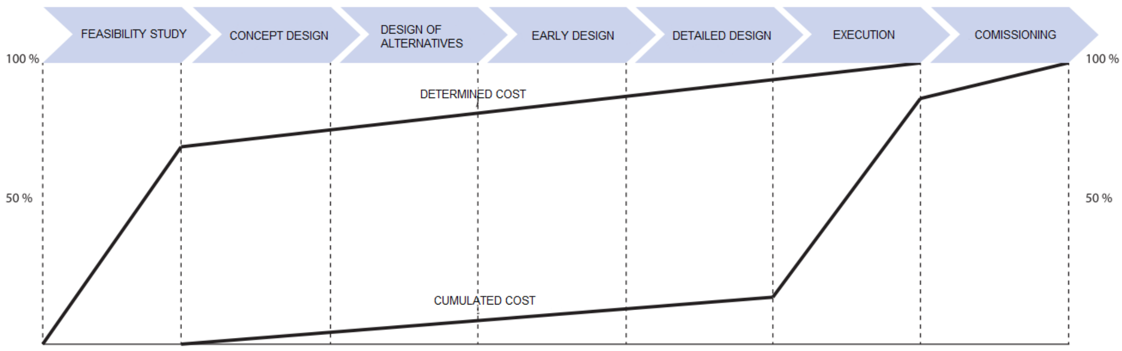

Figure 4. *How costs are determined and cumulate in construction projects. (Translated from RT 10-11226 2016)*

These estimates of cost and time done in early project stages are not 100 % accurate and might change during the project due to design detailing. (Potts 2008) Figure 5 from the Joint Development Board’s publication “Industrial Engineering Projects” shows the accuracy of industrial engineering projects during different phases.

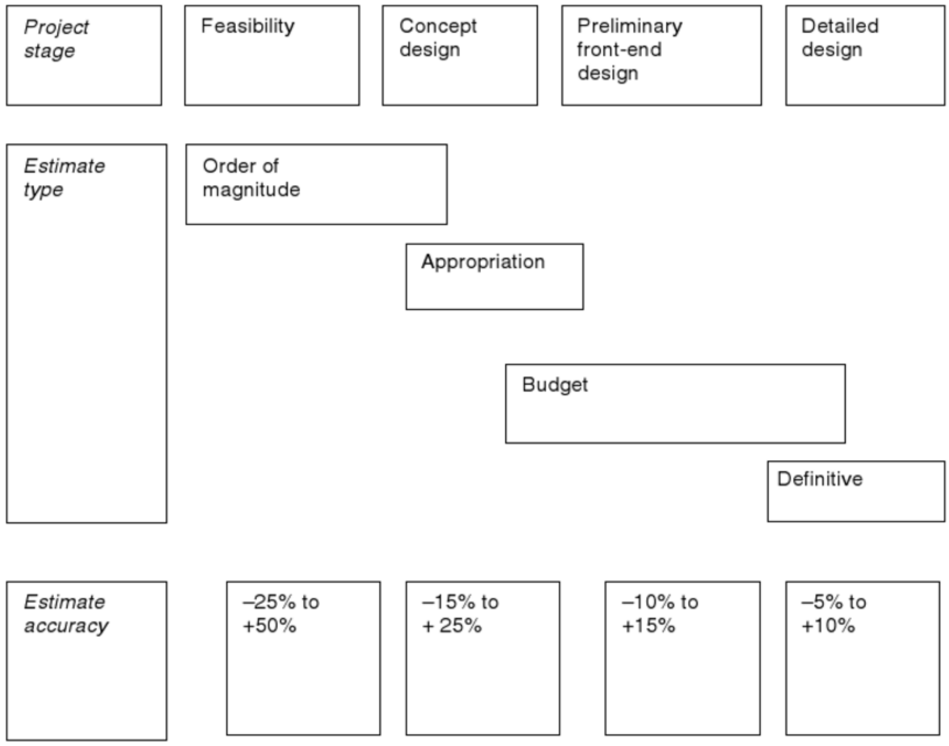

Figure 5. *Estimate accuracy in different project stages. (JDB's figure in Potts 2008)*

Costs are determined in construction projects in an early phase, even though the accuracy could be between -25% to +50%. This leads to target costing. The design should be done in a way that the building stays on budget, but the customer needs are still fulfilled. (Cooper & Slagmulder 1999)

RT 10-11226 explains that costs differ between projects because of furniture and quality standards of spaces, building services, surface structures of spaces and other requirements of use. Pennanen defines six independent cost determining factors on building projects (Pennanen 2012):

1. Usage of spaces and property requirements
2. Designers design of the client's requirements
3. Regional requirements
4. Temporal factors, such as inflation and economic situation
5. Ground conditions
6. Method of production and success on-site

Potts (2008) identifies four main reasons for cost differences: time, quantity, quality, and location. In the design phase these costs can be estimated with functions or performance related way, size related way, elemental cost analyses or unit rate. The method should be chosen depending on the project.

2.2 Cost estimation

The different methods of completing cost estimations differ in construction phases. Cost estimations can be inaccurate in the beginning and become more accurate as the design becomes more detailed. The estimation process, different ways of doing an estimate and cost analyses with benchmarking are presented in this chapter.

2.2.1 Cost estimation by project phases

Investment costs can be estimated by comparing a project to similar finished projects in a feasibility study. Information from previous projects is altered to reflect the new project. Another way of doing an estimation is to use spaces. The project's costs are integrated into the spaces in space estimation. The property developer can also use target costing, where the extent and quality can be altered within the budget limits. (RT 10-11226 2016)

The project's costs can be influenced the most in concept design. At this point the extent and quality of spaces are decided and altered, if they are over budget. The execution time should be decided to determine the building cost index. The location of the building can also reflect on costs, as the cost of labor and materials is dependent on the location. If the location is in the city center, logistics can become more expensive. At this point the target cost is determined by a pre-space program, geological information, special demands, and design targets. The budget of the project with risk factors and add-on costs is created and the investment has financial targets and frames, as well as profit target. (RT 10-11226 2016)

The different designs create the difference in costs in the design of alternatives. Designers should be steered into cost-efficient design with feedback. The design of alternatives is the phase where the costs can be influenced the most in, from the developer's point of view. Target costing, building information modelling or elemental cost estimation can be used for comparing different design options. Costs can be estimated with product information of structural elements in BIM projects.(RT 10-11226 2016)

The estimation of the chosen design can be done with elemental cost estimation in the early design. The cost and impact of the changes should be evaluated for the investment plan, if the developer wants to make changes at this point. After that they can be integrated into the design, if necessary. (RT 10-11226 2016)

In detailed design the production of building is estimated with resources. Resources include amounts and prices and they can be affected by choosing between different production solutions. The cost of the production solution can be calculated with production estimation, which is calculated with the amount of resources and actual prices. These costs can be affected to some extent with procurement solutions. The time aspect is significant.

If the project schedule is tight, there is a larger risk for the main contractor with the subcontractors' schedules. If the schedule has slack, the committed costs grow larger and the developer's income begins later. Cost estimation is modified to be equivalent to the design and procurement packages of the chosen project type. (RT 10-11226 2016)

The main contractor follows and controls the costs during the execution phase. These costs realize through procurement and work phase completion and the main contractor compares these committed costs to their target estimation. This comparison is used for predicting the project outcome and to be used for upcoming procurements and solutions. Additional costs can be created due to design changes, which can lead to additional work and changes. The execution phase ends with the final financial clearance, where the project participants clear out possible cost alterations. (RT 10-11226 2016)

Contractors often do post-processing after the building has been conveyed to the developer. The actual costs are compared to planned costs and the realized data can be used for future projects. (RT 10-11226 2016)

Potts (2008) presents four ways of doing estimates during the design stage. These are function or performance related estimates, size related estimates, elemental cost analyses and unit rate estimates. Functional or performance related estimates use one quantity and one rate, for example a price per pupil in school with 1000 pupils. This kind of estimate is simple but coarse. Size related estimates use gross floor area (GFA). The total floor area is calculated and multiplied by a suitable unit rate per square meter. Areas can be divided by usage to make more precise calculations. Elemental cost analyses are adjusted by time, quantity, quality and location. The cost plan becomes more accurate during the development of the design. The elemental unit rate can be used when the design is more accurate.

A contractor doing a tender should take multiple aspects of design into account, for example the amount and type of work in the project, resources, the design for temporary work, possible alternatives of work methods (prefab/in-situ), risks and funding requirements. At this stage, some of the contracting costs are determined by major subcontracting packages and material prices. The cost estimate includes the net cost of work that include the current rates for laboring materials and construction equipment, the unit or activity rates, the preliminaries or general items and summaries. (Potts 2008)

If the contract type is design and build (D&B), the client's quantity surveyor is responsible for the cost plan at the feasibility and outline proposal stage and the contractor's quantity surveyor for the tender cost plan. (Potts 2008)

2.2.2 Cost analyses and benchmarking

Cost analyses can reveal the cost impacts of design proposals on each construction element. They can be used for comparing similar buildings or construction elements, the cost of design options at an element level or cost modelling design solutions. Data should be collected to be able to do cost analyses. This data can consist of contract details, descriptions of the project, floor areas, the contract sum and the base date and locations of the project. The breakdown of the cost analyses should be at appropriate level, so it is not too complex or too simple. (Davidson et al. 2011)

When multiple cost analysis data is collected, it can be used for creating ranges of likely outcomes and benchmarks. This is possible because specific building elements and sub-elements tend to be common throughout all building projects. (Davidson et al. 2011)

Benchmarking can be described as "*the process of collecting and comparing data within an organization or external to organization to identify the 'best in class'*". (Davidson et al. 2011) Benchmarking was first used in the manufacturing industry for systemically and continuously measuring and comparing against the industry leaders. First the functions to be benchmarked are established, then the competitor or body is identified for the benchmarking tasks. Data is collected and gathered to be analyzed and compared to competitors. Recommendations for improvement are implemented and key indicators are monitored and adjustments are made for the modifications if necessary. (Harris et al. 2013) This cycle is presented in Figure 6.

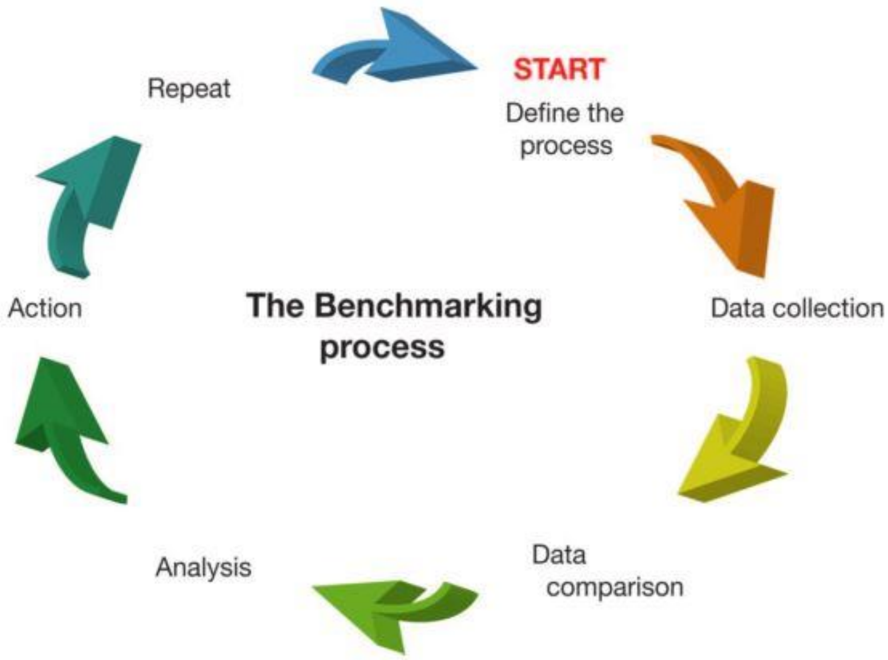

Figure 6. *The process of benchmarking.* (Davidson et al. 2011)

Key performance indicators (KPI) can be used for benchmarking purposes. In the UK KPIs in construction have been measured for over 10 years. KPIs do not concern only cost, they can be customer satisfaction or environmental indicators, for example. The KPIs reveal that 59 % of projects delivered on target or better than the cost agreed on during the start of the construction stage in the UK in 2011. (BIS 2011) Benchmarking often concentrates on cost data, but other aspects of the project can inform the reasoning and results. (Davidson et al. 2011)

2.3 The structuring of cost estimates

An excessive amount of data is created during a construction project and this data should be organized to be able to control and reap the benefits from it. Unlike other countries, The Finnish construction industry uses building elements in order to control costs and quality. (Rakennustieto Oy 2016b)

In this chapter a set of classification systems are presented. These are Finnish Talo 2000, MasterFormat and UniFormat, OmniClass and Uniclass. Many of these are compatible with the ISO 12006 standard.

2.3.1 ISO 12006

ISO 12006 is an international standard for building construction. It is an organization of information about construction work and contains two parts: ISO 12006-2: Framework for classification and ISO 12006-2: Framework for object-oriented information. ISO

12006-3 specifies a language-independent information model. It is used for the development of dictionaries. Information of construction work is stored in these dictionaries (ISO 2015; ISO 2012)

ISO 12006-2 defines a framework for the development of a built environment classification system, but does not provide a complete operational classification system. It is meant for organizations developing classification systems and local variance in details is made possible. It applies to the whole life cycle of construction work. (ISO 2015)

2.3.2 Talo 2000 classification

Talo classification is a Finnish hierarchized format for information exchange in construction meant for all project parties. (Talo-nimikkeistöryhmä & Haahtela-kehitys Oy 2008) The Talo-series has been updated and renewed since 1960s and the newest version is the Talo 2000 classification. (Tiula 2004) The Talo format has multiple principals and goals, such as information exchange between project participants and building maintenance, costs being the main perspective of classes and the classification being partly compatible with ISO 12006-2, and suitability for international projects. The Talo 2000 classification contains four different classifications: project, production, building product and equipment classification. (Talo-nimikkeistöryhmä & Haahtela-kehitys Oy 2008) Additionally the Talo 2000 space classifications; which present the building with premises modules, is the same as the Talo 90 space classification. (Rakennustieto Oy 2016a) The Talo 80 classification is often used by contractors in Finland, although Talo 90 and Talo 2000 have been published.

The Talo 2000 project classification contains premises, building elements and technical components. It is meant to be used as an overall classification for building projects and it has been divided into six main groups:

1. Building Elements
2. Service Elements
3. Project-Related Tasks
4. Property Management Tasks
5. User Tasks
6. Project Provisions

Production classification contains work and installation products. It is used for the execution and procurement of catalogs and calculations and contains 11 main groups. Resource items are used for cost calculation. The basic resources are work (1), materials (2) and equipment (4), which are completed with company tasks (5). Subcontracting (3) is a resource containing all of these resources. (Talo-nimikkeistöryhmä & Haahtela-kehitys Oy 2008) This numbering is established practice.

The premises and space classification contains two individual tables: premises modules and spaces. These tables are meant to be used together. The premises module classification contains main groups with names and numbers. The space models contain 9 groups, such as 1 Residential and Accommodation Spaces. (Rakennustieto Oy 2016a)

Building product classification includes building products remaining in the building and equipment nomenclature includes the equipment for production nomenclatures, as well as general equipment used on-site. (Talo-nimikkeistöryhmä & Haahtela-kehitys Oy 2008)

Table 2 presents an example of different Talo 2000 classification hierarchies. The Talo 2000 project classification can be found in Appendix A and production classifications with the case company's modifications in Appendix B.

Table 2. *Example of the Talo 2000 classification hierarchy comparison.* (Talo-nimikkeistöryhmä & Haahtela-kehitys Oy 2008)

Classification	Main Group	Subgroup		
Premises and Space	Apartments	03:87 Apartment Building's Waste Management Space		
Project	1 Building Elements	12 Building Elements	123 Structural Frame	1232 Bearing Walls
Production	4 Concrete Construction	41 In-situ Concrete Construction		
Building Product	2 Frame Construction Products	21 Concrete Products	211 Reinforcement Products	
Equipment	2 Concreting Equipment	22 Reinforcement Equipment		

Project classification and production classification can be combined for detailed cost estimation and procurement. The Talo 2000 production bill of quantities has been created for this. (Rakennustieto Oy 2010)

2.3.3 UniFormat and MasterFormat

UniFormat and MasterFormat are both publications of the Construction Specifications Institute (CSI) and Construction Specifications Canada (CSA). UniFormat uses functional elements as a base for information arranging and is often used in the preliminary project stage. MasterFormat is used in later project stages and organizes construction requirements, products, and activities. (CSI 2016) The hierarchy of UniFormat and MasterFormat is presented in the Figure 7.

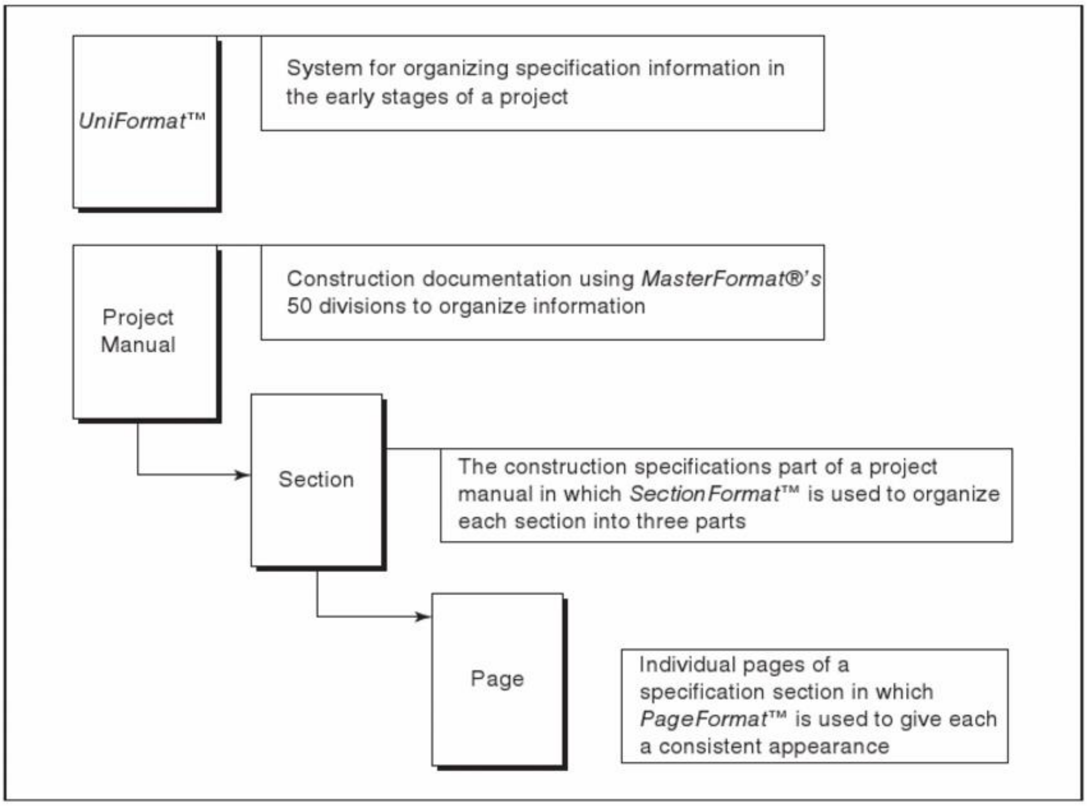

Figure 7. *Hierarchy of UniFormat and MasterFormat.* (Hall & Giglio 2013)

UniFormat was originally created in 1970s by General Services Administration (GSA) and American Institute of Architects (AIA), but today UniFormat is a publication of CSI and CSC. (UPC-SUPPORT INC. 2016a; CSI & CSA 2016c) UniFormat is the most widely used standardized system in building construction and is meant for organizing preliminary construction information. It is based on systems and assemblies and can be used for preliminary cost estimates, cost comparison and analysis. (Popescu et al. 2003; Hall & Giglio 2013) For cost-estimators, UniFormat provides a quick way to see unit prices and it is used for square-foot cost estimation. (Weygant 2011)

UniFormat consists of multiple levels of which the first three can be used on basic preliminary project cost estimates. These are Major Group Elements, Group Elements, and Individual Elements. Levels 4 and 5 are for more detailed listings and provide a checklist. (UPC-SUPPORT INC. 2016b; Hall & Giglio 2013) UniFormat has a combined letter-number – system, where the first letter explains the major group, the second two numbers the group, and the last two numbers the individual element. The Table 3 displays an example of this hierarchy.

Table 3. *Example of UniFormat standardization. (UPC-SUPPORT INC. 2016b)*

Level 1 **Major Group Elements**	**Level 2** **Group Elements**	**Level 3** **Individual Elements**
C. Interiors	C10 Interior Construction	C1010 Partitions

MasterFormat is developed by CSI and CSC, and it has been established as a standard format in construction in North America. (Hall & Giglio 2013; CSI & CSA 2016a) MasterFormat is used in the later stages of design and execution, and concentrates on materials and installation. (Hall & Giglio 2013; Popescu et al. 2003) MasterFormat's cost-breakdown system can be used for estimating and considering costs, but it is not useful for comparative cost analysis, because it only uses equipment and the materials installed. (Popescu et al. 2003) The advantage of MasterFormat is its ability to combine related work tasks under one result and keep this information together. (Weygant 2011) MasterFormat went through a significant update in 2004, thus the structure was expanded to 49 divisions. The five-digit numbering was changed to six digits, or even eight-digit numbering in special occasions. Many architects and specifiers still use the five-digit system, although it is not supported anymore. (Weygant 2011)

MasterFormat has a numbering system with two groups, five subgroups and 50 divisions, if the 00 division is included. The five subgroups are General Requirements, Facility Construction, Facility Services, Site and Infrastructure, and Process Equipment. These subgroups have 49 divisions, but some of them are reserved for future expansion. There are 35 active divisions, most of them under Facility Constructions. (CSI & CSA 2016b) Table 4 presents an example of this hierarchy.

Table 4. *An example of MasterFormat's standardization.* (Weygant 2011)

Level 1 **Divisions**	**Level 2**	**Level 3**	**Level 4**
07 Thermal and Moisture Protection	07 31 Shingles and Shakes	07 31 13 Asphalt Singles	07 31 13.13 Fiber-glass-reinforced Asphalt Singles

UniFormat and MasterFormat can be used together. UniFormat is used in early design for categorizing, when MasterFormat's specific sections are not known yet. UniFormat enables an evolutionary process and later a cross-reference to MasterFormat. There is no one-to-one relationship between these two formats. (Weygant 2011) An example of UniFormat's and MasterFormat's relationship is presented in Table 5.

Table 5. *An example of relationship between UniFormat and MasterFormat.* (Weygant 2011)

Phase	Element	UniFormat™ number	MasterFormat® number	Title
Preplanning	Building enclosure	B30	N/A	Exterior horizontal enclosures
Schematic design	Roof assembly	B3010	N/A	Roofing
Design development	Low-slope roof assembly	B3010.50	07 50 00	Low-slope roofing
Construction documents	TPO roof assembly	B3010.50	07 54 23	Thermoplastic polyolefin roofing

2.3.4 OmniClass

The OmniClass Construction Classification System (OCCS) is used for organizing all information of built environment. The development of OmniClass started in the 1990s by the International Organization for Standardization (ISO) and the International Construction Information Society (ICIS). OmniClass answers to the needs of the construction industry's internationalization and the value and cost-savings presented by BIM. OmniClass tables can be mapped to ISO 12006-2 tables and MasterFormat and UniFormat tables are incorporated with OmniClass. (CSI & CSA 2006) OmniClass offers more detailed information than MasterFormat and UniFormat, and it is more suitable for effective information exchange and collaboration between project participants. Weygant (2011) explains "Standards such as OmniClass™ and IFC pick up where MasterFormat® and Uniformat™ leave off."

OmniClass contains 15 interrelated tables (CSI & CSA 2006):

- Table 11 – Construction Entities by Function
- Table 12 – Construction Entities by Form
- Table 13 – Spaces by Function
- Table 14 – Spaces by Form
- Table 21 – Elements (includes Designed Elements)
- Table 22 – Work Results
- Table 23 – Products
- Table 31 – Phases
- Table 32 – Services
- Table 33 – Disciplines
- Table 34 – Organizational Roles

- Table 35 – Tools
- Table 36 – Information
- Table 41 – Materials
- Table 49 – Properties

2.3.5 Uniclass

Uniclass was first published in 1997. It is used in the United Kingdom and the newest version is Uniclass 2015. Uniclass 2015 is compliant with the ISO 12006-2 standard and can be used in an international context. It includes 11 tables presented in Table 6. Uniclass uses up to eight digits of detailing, which can be used to categorize information for costing. (Delany 2016)

Table 6. *Uniclass 2015 tables and status.* (Delany 2016)

Table	Status and revision information
Co - Complexes	v1.1, Published November 2016
En - Entities	v1.1, Published November 2016
Ac - Activities	v1.1, Published November 2016
SL - Spaces/ locations	v1.2, Published November 2016
EF - Elements/ functions	v1.2, Published November 2016
Ss - Systems	v1.4, Published November 2016
Pr - Products	v1.4, Published November 2016
Zz- CAD	v1.0, Published July 2015
CA - Construction aids	Beta status – consultation ongoing
FI - Form of information	Beta status – consultation ongoing
PM - Project management	Beta status – consultation ongoing

2.3.6 Comparison of structures

OmniClass has a connection with UniFormat and MasterFormat: UniFormat is a legacy source for Table 21 – Elements and MasterFormat is a legacy source for Table 22 – Work Results. Some content of MasterFormat is not included in OmniClass. (CSI & CSA 2006) Uniclass, OmniClass and Talo 2000 are all compliant with the ISO 12006-2 standard. (Delany 2016; Hall & Giglio 2013; Rakennustieto Oy 2016b) Knopp-Trendafilova (2010) has made a comparison between the Talo 2000 (also known as Building 2000 or Construction 2000) and the OmniClass classification, which is presented in Table 7.

Table 7. *Talo 2000 (Building 2000) and OmniClass comparison.* (Knopp-Trendafilova 2010)

OmniClass tables	Basic dimensions of general classification	Building 2000 tables
Table 11 – Construction Entities by Function	Construction Results	In Premises and Spaces Classification
Table 12 – Construction Entities by Form		--
Table 13 – Spaces by Function		In Premises and Spaces Classification
Table 14 – Spaces by Form		--
Table 21 – Elements		In Building Element and Project Classification
Table 22 – Work Results		In Construction Work Section Classification and in Building Resources Classification
Table 31 – Phases	Construction Processes	--
Table 32 – Services		In Building Element and Project Classification
Table 23 – Products	Construction Resources	In Construction Product Classification
Table 33 – Disciplines		--
Table 34 – Organizational Roles		--
Table 35 – Tools		Worksite Equipment Classification
Table 36 – Information		--
Table 41 – Materials		--
Table 49 – Properties		--

As can be seen from this table, OmniClass is a more extensive classification than Talo 2000. Talo 2000 is meant for building products and does not contain information on project infrastructure. Talo 2000 is based on elements, whereas MasterFormat uses work results. (Knopp-Trendafilova 2010) MasterFormat can be used up to eight digits of detailing, whereas Talo 2000 Production bill of quantities (BoQ) uses six digits. (Weygant 2011; Ojala & Kiiras 2010)

2.3.7 Product breakdown system (PBS) and work breakdown system (WBS)

The product breakdown system (PBS) and the work breakdown system (WBS) can be used for project budgeting. WBS and PBS are not the same system, as PBS is the starting point for WBS. PBS is used in the early project stages until the task contents of each component starts to clear out. WBS is often put to use when the contractor takes over from the designers. (Winch 2012) Figures 8 and 9 show examples of PBS and WBS structures using Uniclass tables.

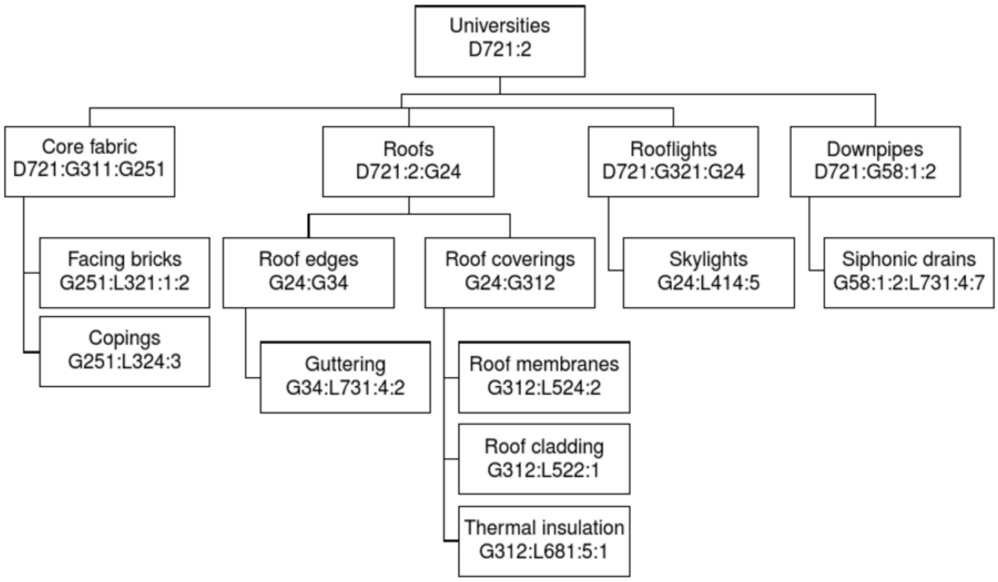

Figure 8. *Product breakdown system using Uniclass.* (Winch 2012)

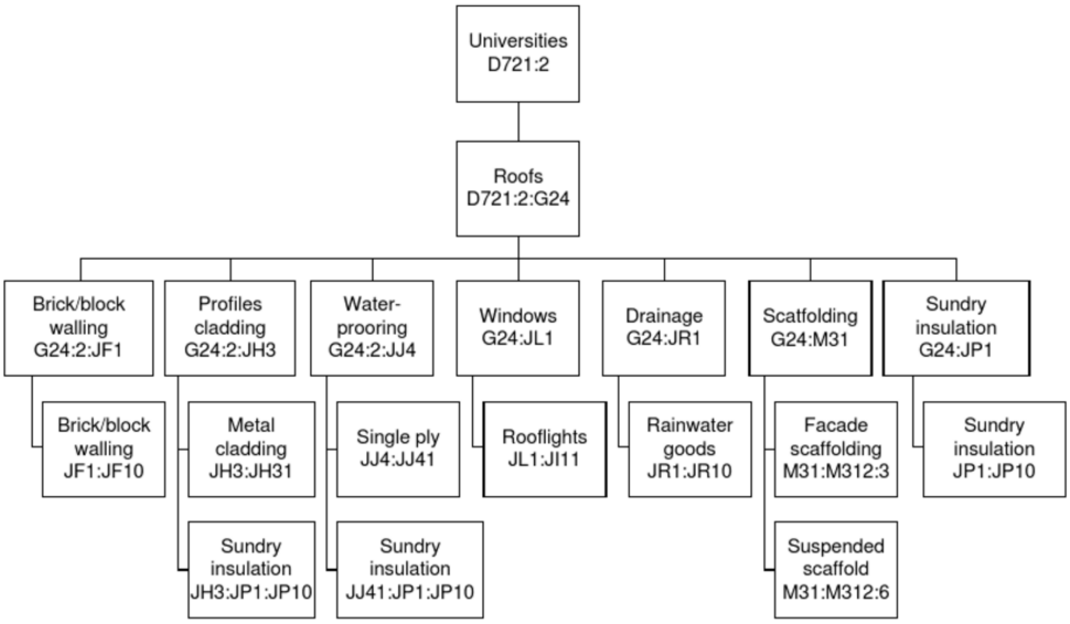

Figure 9. *Work breakdown system using Uniclass.* (Winch 2012)

PBS progressively breaks down the components of which the facility consists of. PBS is the natural form of presenting the budget for the client, because they are interested in the product they receive. It is the heart of cost planning and management. The bill of quantities (BoQ) is the lowest level of detail for PBS. (Winch 2012)

WBS is used for budgeting and uses Uniclass or another classification system to identify a code for each task. WBS consists of levels, where the first level is the trade-packaging level, unless sub-areas are needed for site. The next level can be a whole trade task, for example Roofs in Figure 9. Below this are the particular elements, of which the finest level is the weekly tasks. The elements in WBS are broken down into three elements: the costs of labor, materials and plant required for the execution of the task. This is known as a cost breakdown system (CBS). (Winch 2012) CBS shows the costs of each level, that add up to the top. (Lester 2007) Figure 10 presents an example of CBS.

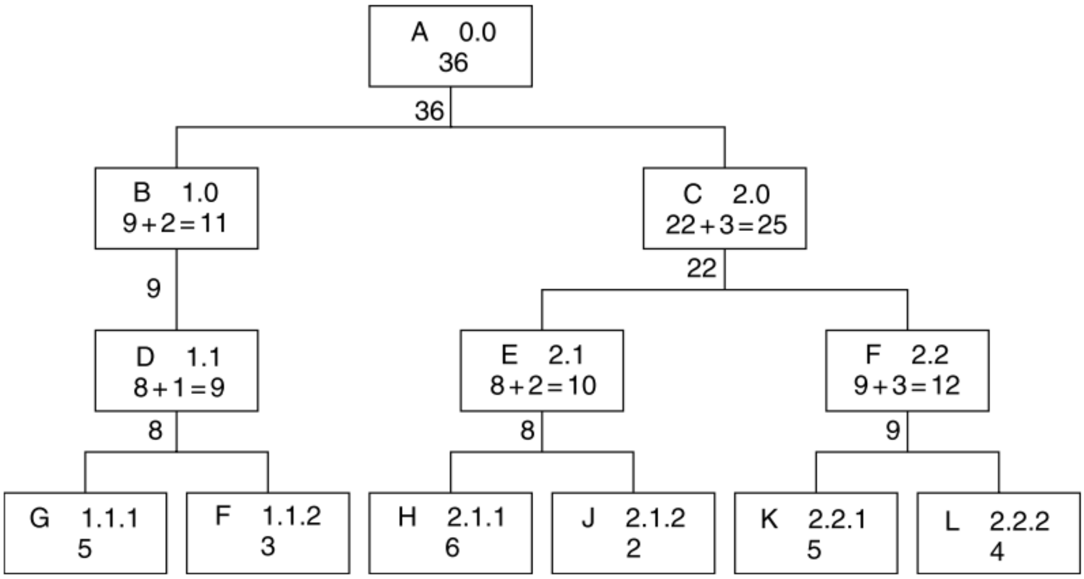

Figure 10. *Cost breakdown system.* (Lester 2007)

The highest level of detail can be achieved if WBS and CBS are combined into a matrix. When the person responsible is added to this, the combination is called an Organizational Breakdown System and creates a cost control tube. (Winch 2012)

2.4 Cost controlling

The three purposes of a construction cost controlling system are to provide the means for comparing actual cost with budgeted costs to show the possible inaccuracies to be acted on, to develop a database of productivity and cost performance data which can be used in future estimations, and to generate data for valuing variations and changes to the contract and potential claims for additional payments. (Bennet 2003) Cost controlling is not a complete system, but a part of the whole management cost and control system (MCCS). Instead of monitoring and recording data, it should also include the analyzing of data. Analyzed data can show the possible problems to be acted on. (Kerzner 2013) Controlling a project requires controlling of schedules, progress, budgets, and incurred costs. (Westney 1997)

Project management must compare the cost, time, and performance of the project to budgeted cost, time, and performance. This should be done in an integrated way, not just individually. Time, cost, and performance are the three resource parameters (Kerzner 2013)

Potts (2008) sums up six characteristics that an effective cost control system should have:

- A project budget, set with contingency figure to be used at the discretion of the responsible project manager
- Costs should be forecasted before decision-making to allow the consideration of all choices
- The cost-recording system should be cost-effective to operate
- Actual cost should be compared with forecasted cost at appropriate periods to ensure conformity with the budget and to allow for corrective actions if necessary and if possible
- Actual cost should be subject to variance analysis to determine a reason for any deviation from the budget
- The cost implications of time and quality should be incorporated into the decisions-making process

The three main types of a contractor's project cost control systems are presented in this chapter. These are cost-value reconciliation, unit costing and earned value management.

2.4.1 Cost-value reconciliation (CVR)

Cost-value reconciliation is used by building contractors and shows the profitability of a company using established totals of costs and value together. (Potts 2008) Cost can be defined as the total money, time and resources that are associated with a purchase or an activity. Value can be defined in accounting terms as the monetary worth of an asset, goods sold, service rendered or liability or obligation acquired. For a project, value is much more, and it includes tangible aspects such as cash to reduce borrowing, turnover to demonstrate to shareholders, and overhead contribution that the activity makes. Value in construction is hard to define, as there is a gap between work done and payment received. There is also the aspect of quantities and unit rates being approximated, which leads to the unit cost of activities being just approximate. (Ross & Williams 2012)

CVR has two purposes: forming the basis of a statutory account and providing information for management. This management information can assist in the identification of problems, the need for reserves, the reason for loss, and information to prevent repeating such losses. (Potts 2008) CVR is done at each interim valuation date, for example monthly. Total costs to date are compared with the total valuation, and necessary adjustments should be made for under- or overvaluation. The disadvantage of CVR is the lack of breakdown of cost/profit figures between types of work or locations within the project. (Potts 2008)

2.4.2 Unit cost

Contract variance - unit costing is used by civil engineering contractors. In unit costing, actual costs can be divided by the quantity of work they present to compare actual unit costs with tendered unit costs. The comparison is done between the value of work done and the cost of doing it, on monthly bases. The purpose of this is to identify problem areas and forecast the outcome of the project. If the work is ongoing, the problems can be acted on to try to prevent possible losses. (Potts 2008) Miscellaneous costs should also be recorded and allowed in to the system. They can be proportionally added to other work types, if needed. (Harris et al. 2013)

2.4.3 Earned value management (EVM)

In 1966 the United State Air Force mandated earned value as a part of other planning and controlling requirements in their programs. After this earned value management became a fundamental approach. First the requirement was called Cost/Schedule Planning Control Specification (C/SPC), but is now known as the Earned Value Management System (EVMS) with 32 guidelines in the EIA-748 Standard. (Humphreys & Associates Inc. 2012)

Earned value management (EVM) integrates schedule and costs, and compares planned work with accomplished work. (Potts 2008; Ross & Williams 2012) There are more than a few terms used in earned value management, which are the following: (Humphreys & Associates Inc. 2012; Potts 2008):

- Budgeted cost for work scheduled (BCWS), also known as planned value (PV)
- Budgeted cost for work performed (BCWP), also known as earned value (EV)
- Actual cost of work performed (ACWP), also known as actual cost (AC)
- Budgeted at completion (BAC)
- Estimate at completion (EAC), which is ACWP to date added with the estimate to complete remaining work

These terms can be used to calculate variances (Humphreys & Associates Inc. 2012; Potts 2008):

- Cost variance (CV) = EV-AC or BCWP-ACWP
- Schedule variance (SV) = EV-PV or BCWP-BCWS

If the result of these calculations is greater than 0, the result is favorable (an underrun or ahead of schedule). If the result is negative, the outcome is unfavorable (an overrun or behind schedule). (Humphreys & Associates Inc. 2012; Potts 2008) There is also the variance at completion:

- Variance at completion (VAC) = BAC-EAC.

If the result is greater than 0, the outcome is favorable and if under zero, unfavorable. (Humphreys & Associates Inc. 2012)

There are two performance efficiency indexes, cost and schedule. To get an indication of the value of money, earned value is divided by actual cost (EV/AC). The result is called the cost performance index (CPI). If the result is greater than one, the physical progress is being accomplished with less than the forecasted cost. The indication of the schedule is called schedule performance index (SPI), which can be calculated by dividing earned value with planned value (EV/PV). If the result is greater than one, progress was faster than planned (Potts 2008; Kerzner 2013)

EVM's benefits are (Ross & Williams 2012; Potts 2008; Anbari 2003):

- Single management control using reliable data
- An accurate display of the project status, which enables senior management to identify the performance of the project as a whole or in parts
- Early and accurate identification of trends and problems
- A basis for the project's course correction

There can be problems with earned value management. Lukas (2008) listed reasons for earned value analyses failing by his experiences. Most of the problems concerned the inadequate use or lack of information, such as requirements, WBS, budget or schedule. Also change management and management influence were mentioned. (Lukas 2008)

2.5 Financial performance

It is vital for a construction company to be able to report the true position of individual projects. This information is needed for mandatory reports and informing shareholders as well. Still the reporting of the financial position of projects can be problematic or even misleading, if the estimator modifies the figures to seem better than they are in reality. (Ross & Williams 2012)

2.5.1 Cash flow forecasting

Cash flow management is a crucial part of a construction company's financial management. There are two kinds of cash flow forecasts: organizational cash flow forecast and project cash flow forecast. Organizational; also known as company's cash flow forecast, is used for business and resource planning and it can also tell the financial health of the company. (Garner et al. 2011) Forecasting can be made for a period of time, for example a year, and if the company's cash flow forecasting is done efficiently and without great effort it is possible to do forecasting quarterly or monthly. (Garner et al. 2011; Harris et al. 2013)

Simply put, the cash flow forecast estimates the timing and amount of cash inflows and outflows over a specific period of time. Cash inflows include the payment for work done and work completed, payment for materials on-site and payment from other organizations for services offered. Cash outflows include payment for materials, payment to subcontractors, staff salaries, repayment of loans and the purchasing of capital equipment. (Ross & Williams 2012) The client can pay the contractor for certain work stages completed and the contractor must pay the subcontractors for work done. There is a time lag between these payments which must be considered when estimating the cash flows.

There are several techniques for cash flow forecasting and the contractors should use the more sophisticated ones. During execution, cash flows are influenced by multiple factors, such as cost overruns, time delays, variations, and technical changes. Cash flow forecasts should provide an accurate, flexible and comprehensible forecast. (Ross & Williams 2012)

A company can calculate the cash flows of their projects and combine them with head-office cash flows to estimate the overall company cash flow. For project cash flow, the following information is required (Harris et al. 2013):

- Value vs time graph
- The measurement and certification interval
- The payment delay between certification and the contractor receiving cash
- The retention conditions and retention repayment arrangements
- Cost vs time graph
- The project costs broken down into above items
- The delay between incurring a cost liability under each cost heading and meeting that liability

For overall company cash flow forecast, the information required in addition to those mentioned previously, are the head-office incomes and outgoes and the time of their occurrence. (Harris et al. 2013)

In 1978 Hudson developed two parameters “DHSS expenditure model” for forecasting cash flows. The S-curve based on this is well acknowledged and there are alternative formulates available. (Ross & Williams 2012; Garner et al. 2011) An example of an S-curve is presented in Figure 11.

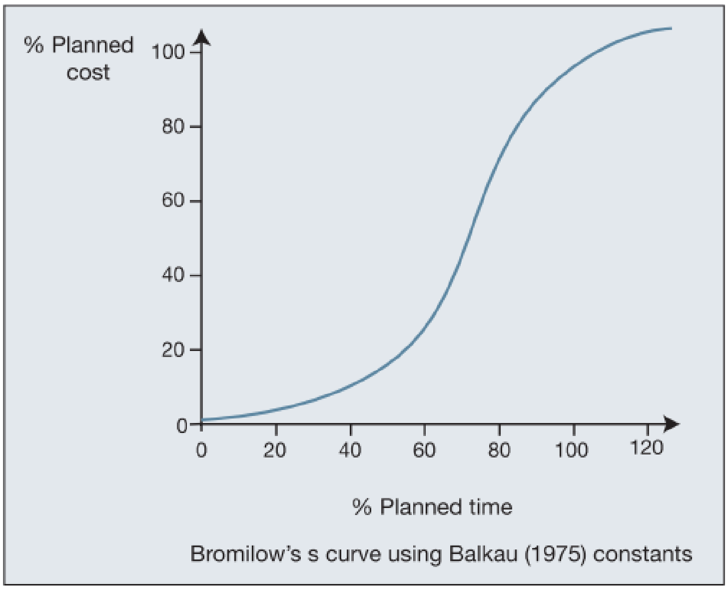

Figure 11. *Example of an S-curve.* (Garner et al. 2011)

3. 5D BIM – MODELLING AND MANAGEMENT

Building information modelling (BIM) can be defined as *"a modelling technology and associated set of processes to produce, communicate, and analyze building models."* (Eastman et al. 2011) or "*A technology that allows relevant graphical and topical information related to the built environment to be stored in a relational database for access and management*". (Weygant 2011) BIM is not just 3D models; the model should contain object attributes, or so to say, intelligence at an object level. (Eastman et al. 2011)

This chapter describes the evolvement of building information modelling from the 1960s to present day. Interoperability is explained, because it is an essential part of collaborative work flows of BIM. 5D BIM is introduced with the benefits and barriers it carries out. A set of current 5D BIM applications are presented at the end of this chapter.

3.1 Background and development of BIM

Modelling 3D geometry have been researched since 1960s and building model based 3D solid models were developed in the late 1970s and early 1980s. These solid modeling CAD systems were developing, but the building industry did not take use of this new technology, as 2D CAD had become the common way of working and 3D designing was foreign for most designers. In addition, the systems required were quite expensive. (Eastman et al. 2011)

Object-based parametric modeling was the major change for the building industry. It enabled rules and conditions in modeling. (Eastman et al. 2011) For example, a window placed in a wall creates an opening for the window. If the window is moved, the opening moves with the window and the wall "recovers". At the same time the window and wall can have user-defined information in them, for example the length of the wall or the U-factor of the window.

In the late 1980s research concentrated on developing the technology and collaborative data exchange methods and standards. (Penttilä et al. 2007) The first Finnish BIM projects were piloted in the early 2000s by Senaatti properties and one of these was the extension of the TKK's (currently known as Aalto University School of Science and Engineering) main building. (Hänninen et al. 2010) National standards for applying BIM in construction projects started to appear in the late 2000s and one of the first ones was the Senaatti Properties BIM Standards. The first BIM standards are presented in Table 8.

Table 8. National standards by publishing year. (Modified from (Hakanen 2014)*)*

Standard	Published
United States National BIM Standard	2007
Senaatti Properties BIM standards, Finland	2007
The Hong Kong Institute of BIM	2009
AEC (UK) BIM Standards	2009
National Guidelines for Digital Modelling, Australia	2009
Statsbygg BIM Manual, Norway	2011
Common BIM Requirements 2012, Finland	2012

4D models and tools were developed in the late 1980s by large organizations. Custom and commercial tools evolved in construction in the mid- to late 1990s. 4D models were manually created with automatic links to 3D geometry, entities and groups of entities for construction activities. (Eastman et al. 2011) The construction company HOAR used 5D cost estimates as early as in 2008. It was not immediately used in other projects of the company. (Sattineni & Macdonald 2014) An imprecise timeline for BIM is presented in Figure 12.

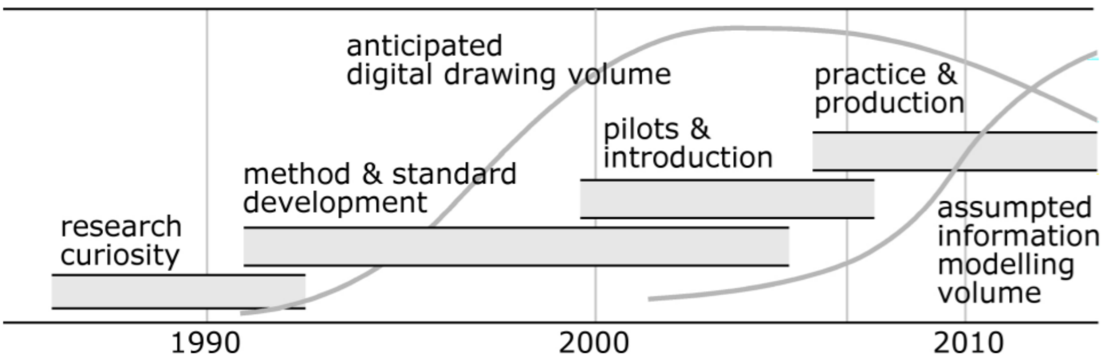

***Figure 12.** BIM framework as a trend or phenomena within the AEC-field.* (Penttilä et al. 2007)

3.2 Interoperability

Different modeling applications have overlapping data requirements supporting various tasks of design and construction. Interoperability is needed to be able to exchange this data between applications. The two widely acknowledged international standards for building product data models are Industry Foundation Classes (IFC) and CIMsteel Integration Standard Version 2 (CIS/2). IFC is meant for building planning, design, construction and management whereas CIS/2 is for structural steel engineering and fabrication. These both are already important internationally recognized standards for interoperability between different partners and parties of construction operations. (Eastman et al. 2011)

IFC uses the ISO-STEP EXPRESS language and addresses the data structures dealing with geometry, relations and attributes. (Eastman et al. 2011) It is developed by the buildingSMART organization and the commonly used version is IFC 2x3, even though a newer version called IFC 4 has been published. (buildingSMART Finland 2017) IFC has a long history and the development is ongoing. (Laakso & Kiviniemi 2012)

The users of BIM have found difficulties working with IFC. It does not transfer working parametric objects and the objects exported to IFC cannot be modified. It is not useful for as-built changes. It exports size dimensions, but does not know the geometric entities are controlled by the dimensions. (McPhee 2013)

3.3 Benefits and barriers of 5D BIM

There are several studied done on the benefits and barriers of 5D BIM. Some of the studies focused on the implementation of 5D BIM whereas some concentrated on the practicability of 5D BIM itself. This chapter presents these benefits and barriers found in these studies.

Lee et al. (2016) have studied the practicability of 5D BIM and identified limitations in different stages of BIM. These results can be seen in Table 9. The study predicts that significant amount of information can result in complexity and non-BIM-capable stakeholders will have limitations in benefiting from 5D BIM.

Table 9. *Practicability of 5D BIM. (modified from* (Lee et al. 2016)*)*

Stage	Process	Criteria	Observation
MODEL	Collection and Input of Building Information into 3D Model	modelling effort	neutral
		inter-operability	poor
		information output	good
		limitation	Non BIM-capable stakeholders will face obstacles to proceed to stage 2.
COST	Input of Information for Cost Estimation	modelling effort	good
		inter-operability	neutral
		information output	good
		limitation	Cost information cannot be automatically updated by suppliers.
TIME	Input of Information for Time Scheduling	modelling effort	neutral
		inter-operability	good
		information output	good
		limitation	Requires site knowledge and localized experience to have realistic output.
VIRTUALISATION	Virtualisation of 5D Building Information Modelling	modelling effort	neutral
		inter-operability	good
		information output	good
		limitation	Modelling process still difficult when handling large amount of information.

Popov et al. (2010) have studied the use of the Virtual Project Development concept and developed the implementation of the Project Management concept in the 5D environment. They present the advantages in the use of BIM according to the 5D concept during the whole product lifecycle, some of which are presented below. (Popov et al. 2010)

- Both graphical views and information is managed by BIM, which enables computer-aided use of drawings, reports, design analysis, evaluation, scheduling, organization of work and facilities management
- Information creation and sharing over the entire lifecycle. Collaborative environment which eliminates data overlap, the need for re-entering data, data loss, miscommunications and translation errors

- The user is provided with the possibility to evaluate economic expenditures at any stage of project
- The Product Lifecycle Management (PLM) concept allows you to calculate precisely the demand for resources, to determine the schedule and to identify the effective alternatives based on the 3D model

Liu et al. (2014) identify the following challenges in automatization of BIM-based full-detailed cost estimation and schedule planning (Liu et al. 2014):

- Temporary facilities are not modelled, which means that the quantities of formwork or scaffolding, for example, cannot be extracted from the 3D model
- It is difficult to model temporary facilities, as they require construction knowledge. The BIM program should have the "intelligence" inside to be able to automatically build a 3D model of these temporary facilities
- The difference between BIM-based quantity takeoff and downstream analysis, such as estimation, which uses the quantities with product and process models

Sattineni & Macdonald (2014) studied the HOAR constructions company's challenges in implementing 5D BIM. The company's VDC team emerged in 2011 but the first 5D estimate was done in 2008. The company used Vico Software as their 5D BIM solution. The challenges found in this study are presented below.

- There was no BIM software available that could perform all the functions that BIM could enable at the time of this study. This lead to the 5D BIM team to assisting the projects using 3D and 4D BIM
- Persons of technological expertise and construction knowledge were needed
- The senior management was hard to convince of the value of using 5D BIM because of the higher costs
- There was human reluctance to change. Training can be challenging and this was further complicated by the need for the company to remain profitable at the same time as these new processes were explored

There were benefits as well: The company had never had as much data about their own internal processes, and the VDC team could provide much faster feedback to their design counterparts for cost planning purposes. The company definitely wanted to continue with the implementation of 5D BIM. (Sattineni & Macdonald 2014)

3.4 5D BIM software providers

5D BIM models can be created with several software tools. (Lu et al. 2016; Abanda et al. 2015) This report presents a few of them: iTWO, Vico Office and Autodesk Navisworks.

iTWO is a product of German RIB Software AG, a company founded in 1961. iTWO is a 5D BIM enterprise solution for construction companies, industrial companies, developers and investors. (RIB Software AG 2016a) iTWO uses Construction Process Information (CPI) technology that combines geometry with alphanumeric qualities. It integrates CAD applications on one side and ERP systems on the other. (RIB Software AG

2016b) It is an end to end -solution and has multiple modules used for different purposes. The usage of iTWO is presented in chapter 6. iTWO's interfaces are presented in Figure 13.

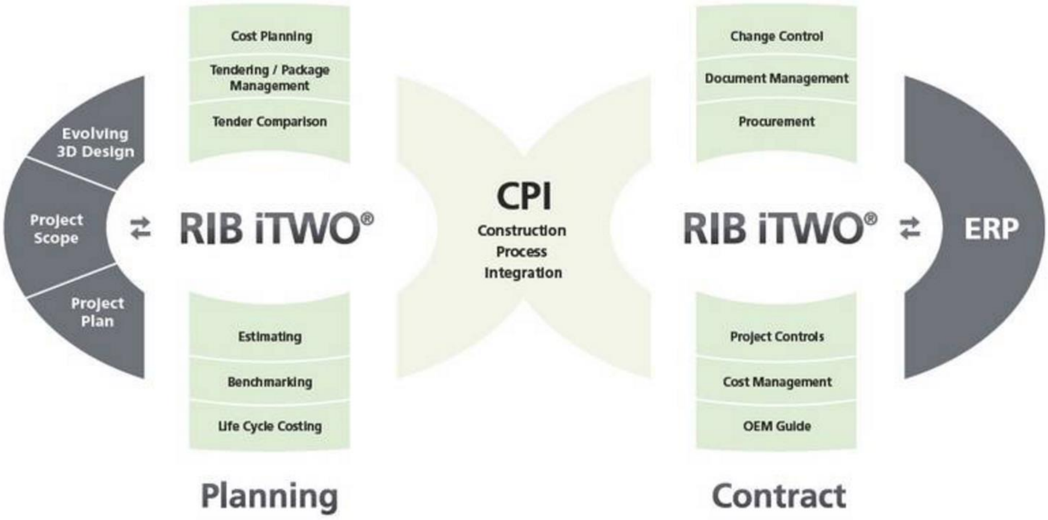

Figure 13. *RIB iTWO's interfaces.* (RIB Software AG 2016b)

Vico Software was founded in 2007 and became a part of Trimble Navigation Ltd in 2012. Vico Software is an integrated approach to coordination, quantity takeoff, cost estimation, project scheduling, and production control. (Vico Software 2016a) It uses multiple modules used for different parts of the workflow. For 5D estimating, Vico Office has two model-based applications: Vico Cost Planner, which is based on Target Cost Planning, and Vico Cost Explorer which is a budgeting application that shows the aspects contributing to cost changes visually. (Vico Software 2016b) Vico Offices modules are presented in Figure 14.

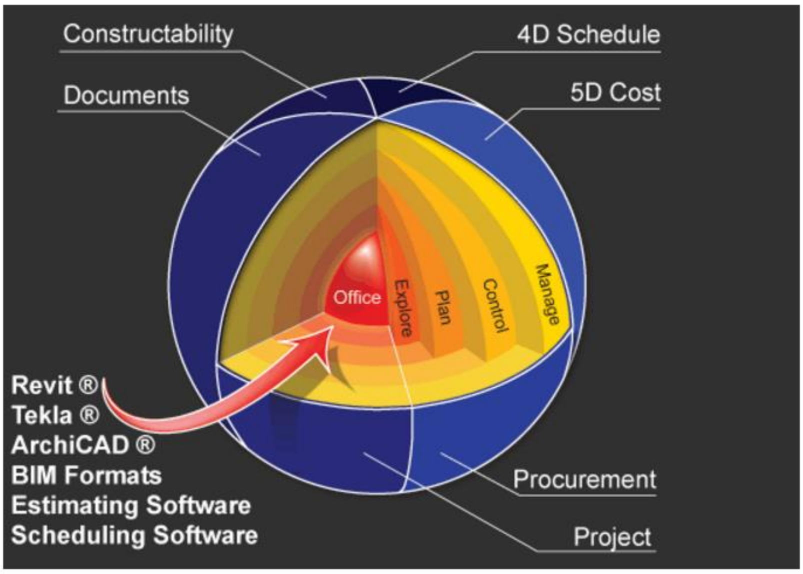

Figure 14. *Vico Office modules working together.* (Vico Software 2016b)

Navisworks is a product by Autodesk and is meant for project review for AEC professionals. Users can import times, dates, costs and other task and dynamically link schedules with project modules. (Autodesk 2016) A screenshot of Navisworks is presented in figure 15.

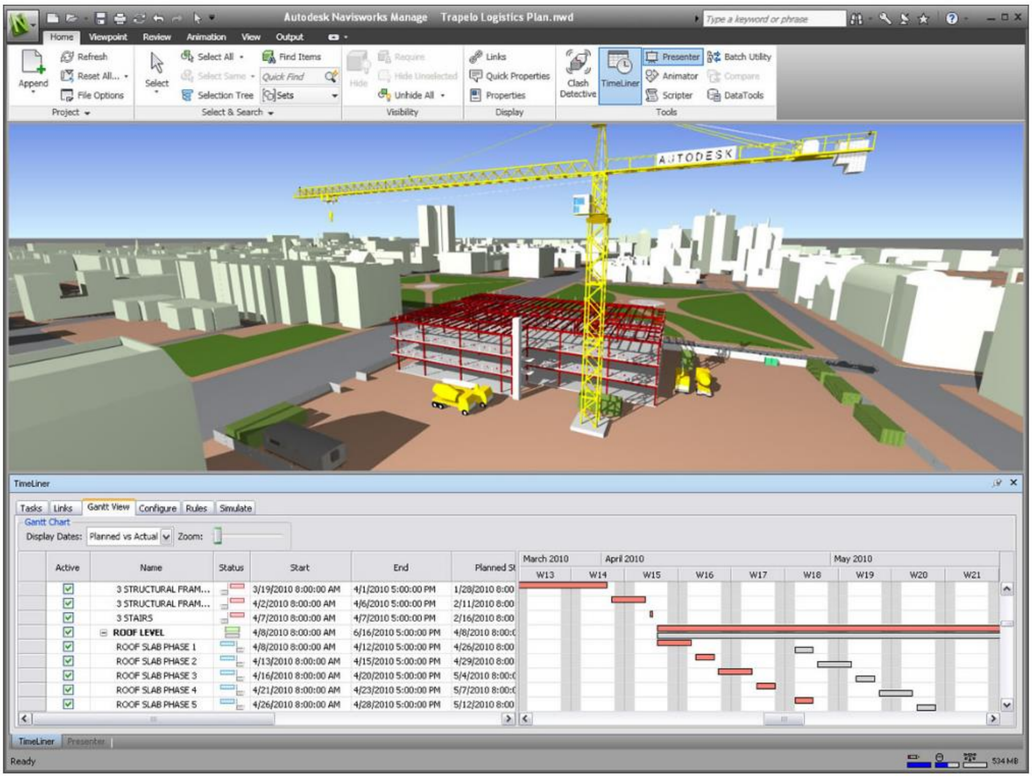

Figure 15. *Navisworks 5D project scheduling.* (Autodesk 2016)

4. METHODS AND CASE COMPANY

This thesis uses qualitive methods and contains theoretical research, including literature review and case study with demonstration of the chosen cost data model consisted in the 5D BIM application. Qualitive research is usually performed adaptively and can be changed if needed. The research participants are selected for the research instead of being randomly selected. Case studies usually represent a phenomenon as accurately as possible. (Hirsijärvi et al. 2009) In this chapter the case company and data collection methods are presented.

4.1 Introducing the case company

The case company Fira Oy is part of the Fira Group Oy. Fira Group consists of two individual companies, Fira Oy and Fira Palvelut Oy, presented in Figure 16. Fira Palvelut specializes in pipeline renovations and introduced the two-week pipeline renovation in 2016. The renovation was highly prominent in Finnish media. (Fira Oy 2016b)

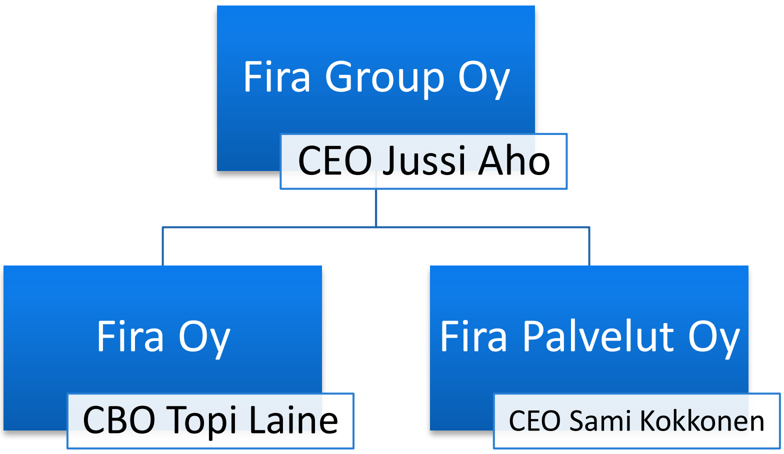

Figure 16. *Fira Group's corporation structure.*

Fira was founded in 2002 and their three values are caring, trust and transparency. The company focused on improving the founders' professional skills and specialized know-how in the first phase. The second phase, which started in 2009, focused on the clients. The company wanted to find the means to better serve and give value to their clients. The current phase concentrates on "building a smarter society together". Fira's (including Palvelut) revenue has grown from 73,1 M€ to 135,8 M€ in two years. (Fira Oy 2015) Fira's services are presented in Figure 17.

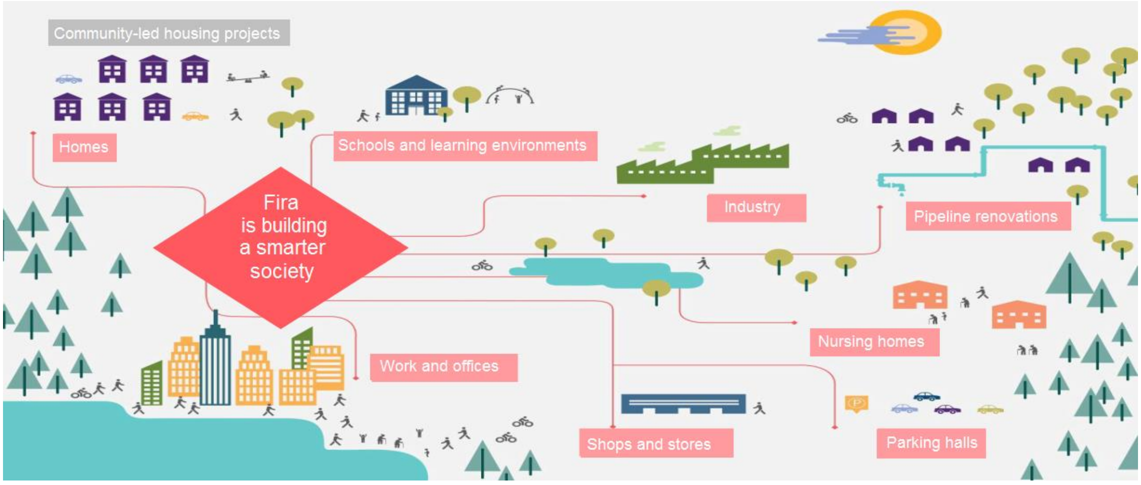

Figure 17. *Fira's services. (Translated from Fira's introduction presentation)*

Fira does not own lots and does not do housing projects of their own. They have a customer-oriented project development and design service called Verstas (workshop in English). Verstas uses a virtual design environment and the design is done using BIM tools. (Fira Oy 2017) Almost all of Fira's projects on new buildings use building information models. Fira also uses cost estimation modeling in Verstas, which means that Fira's experts model the most expensive parts of the building and this is used as the basis of the cost estimation. Cost alterations can be identified during the design stage. (Isoherranen 2012)

4.2 Literature Review

The literature review had two main themes: construction cost management and 5D BIM. These two themes are related to each other, but finding literature combining the two themes was challenging. Most of the literature used in this research was from the 2000s and onwards. 5D BIM related literature was mostly written after 2010, because 5D BIM is not commonly used. The literature used in the research was mostly international, but Finnish references were used as well.

The construction cost and financial management were studied in the first part of the literature review. Different methods for estimation and reasons for differing prices were presented. National and international structures for construction information were presented and compared. A set of cost controlling methods were introduced with financial analyses.

5D BIM and the development of BIM were studied in the second phase of the literature view. The benefits and barriers of 5D BIM are presented as well as some of the applications using it. interoperability and the use of the IFC format were discussed.

The literature review acts as the basis for this study. It helps in understanding the research questions, but does not offer a simple all-inclusive answer. The literature review offers methods and targets for the use of the case company. It also connects this study to other research conducted in this field.

4.3 Case study

The case study was carried out by development assignment and demonstration of the 5D BIM application with the chosen cost data model. The researcher has spent two days a week in the case company's RIB iTWO development project from September 2016 to March 2017. This included workshops, participatory information gathering and a questionnaire. The project was established in fall 2016 to implement RIB iTWO solution to use in the case company. The problem to be resolved was how to implement the solution in the best possible way. The project participants are experts of the company in their area. Some of them were named as Super Users and their roles were more significant. They would become experts in using iTWO and train the new users. The project participants are presented in Table 10.

Table 10. *iTWO development project participants.*

Job Title	Area of Expertise
Project Manager	Management of the development project
Production Modeler	Virtual Construction and Design (VDC)
BIM Specialist	Structural design, cost estimation models
Cost Controller	Execution cost controlling
Head of the Cost Estimation Team	Cost estimation, quantity survey
Project Manager	Design management
Purchasing Engineer	Procurements
Site Engineer	Execution, BIM
Software Architect	IT and ERP systems

The development assignment included questionnaire, conversations with the participants, notes and a recorded session before starting this research. The questionnaire consisted of eight parts, where different modules and combination of modules in iTWO were graded and their possibilities and problems were described by participants. These modules and combination of modules were the BIM Qualifier, Element Planning, Tender/Job Estimate, Procurement, the Activity Module, Execution, Controlling and iTWO in its entirety. There were also statements about iTWO, which the participants could choose from. The questionnaire was sent to 11 development project participants: The Super Users, a process engineer and a business analysist. There were nine answers, but the participants did not have to answers to all questions, if they felt that they did not an opinion or enough experience.

The project was closely executed with the consultants from RIB. Their role was to help the implementation of the solution and answer the questions that arose. All project participants became certified iTWO users. The information gathered included the decisions made and the reasons behind them throughout the project. The project was documented in a shared file with workshops and questions and answers to the consultants.

The demonstration uses the cost data model and data created during the development assignment to test the potential cost control tools on an actual ongoing project, presented in Figures 18 and 19. The selected project contains three residential buildings and a parking hall in Helsinki. There are two different clients and two of the buildings contain only rental apartments. The project started in the beginning of 2016 and the last part will be handed over in early 2018. A segment, building 2A, is used in this case study. The case study is only concentrates on the light partition walls and their puttying and painting. The simulation project created in the development project team is used to test out the possibilities of comparison between projects.

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Figure 18. *Illustration of the case building. (Konkret Architects Ltd., 2016)*

Background information is gathered before starting the demonstration. This information contains the contracts, prices and other information of the light partition walls. Information needed to execute the project in iTWO is documented. An architectural model of the project is imported into iTWO. The model is used to create the bill of quantities (BoQ) and a cost estimation is created using the company's cost database. A schedule is done in iTWO using the actual schedule of the project as a basis. The realized costs and work done are reported in iTWO to create the financial analysis. The report periods are January 2017 and February 2017. A demonstration of the workflow in iTWO is created in this case study.

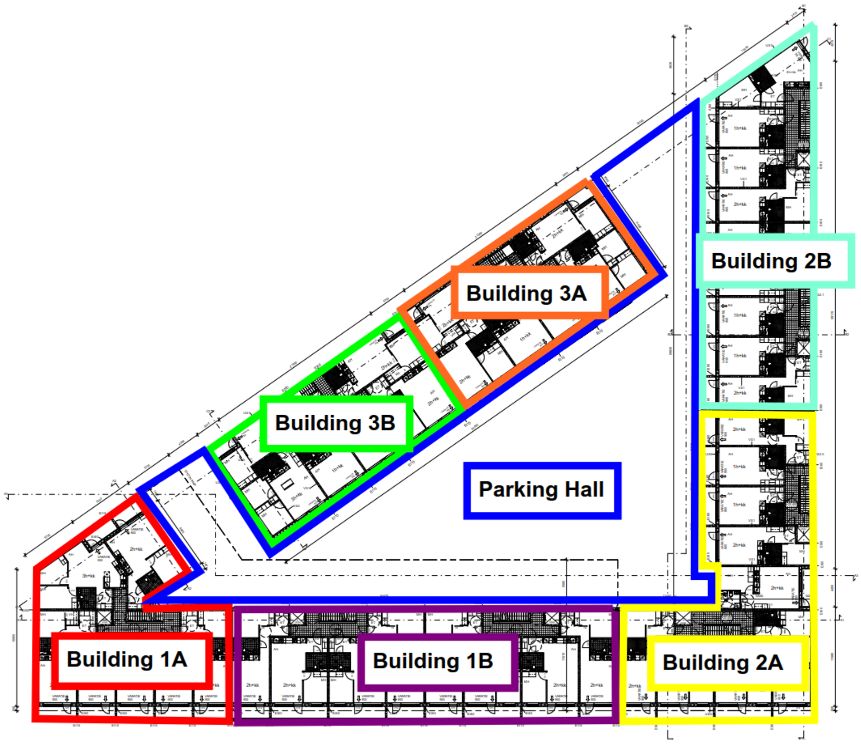


Figure 19. *Case project's blueprint.*

Several applications are used in the case study, besides of iTWO. These are presented in Table 11. These applications are used in the ongoing case project.

Table 11. *Applications used in the case study besides iTWO.*

Product	Function
Simplebim	IFC model modifications.
Solibri Model Checker	Information take offs from IFC models
Tocoman Kustannusraportointi	The case company's tool for cost reporting
Tocoman Aikataulu	The case company's tool for scheduling

5. CREATING FINANCIAL ANALYSIS IN 5D BIM

The construction industry has started to digitalize and several BIM systems have been developed. (Abanda et al. 2015; Gerbert et al. 2016) The case company decided on having a new system to benefit from virtual design and construction (VDC). RIB iTWO was selected and even though it contains many features, this action research concentrates mainly on the financial analysis. This chapter explains the data management in iTWO and what has been considered and decided during the RIB project. The latter part of this chapter presents the demonstration, where a part of a project is tested in the iTWO with the cost classification structure decided in the RIB project.

5.1 Data management in iTWO

iTWO uses two types of databases: master data and enterprise databases, which are presented in Figure 20. Master data can have the data structures, the cost database and other information that can be used as the basis of new projects. Project alternatives can be created to compare different options, for example real case and worst case scenarios. A new project is created when a project is moved from the tendering phase into a contract. The progress of the project is reported to the enterprise database, which is used for financial analyses and comparison between projects.

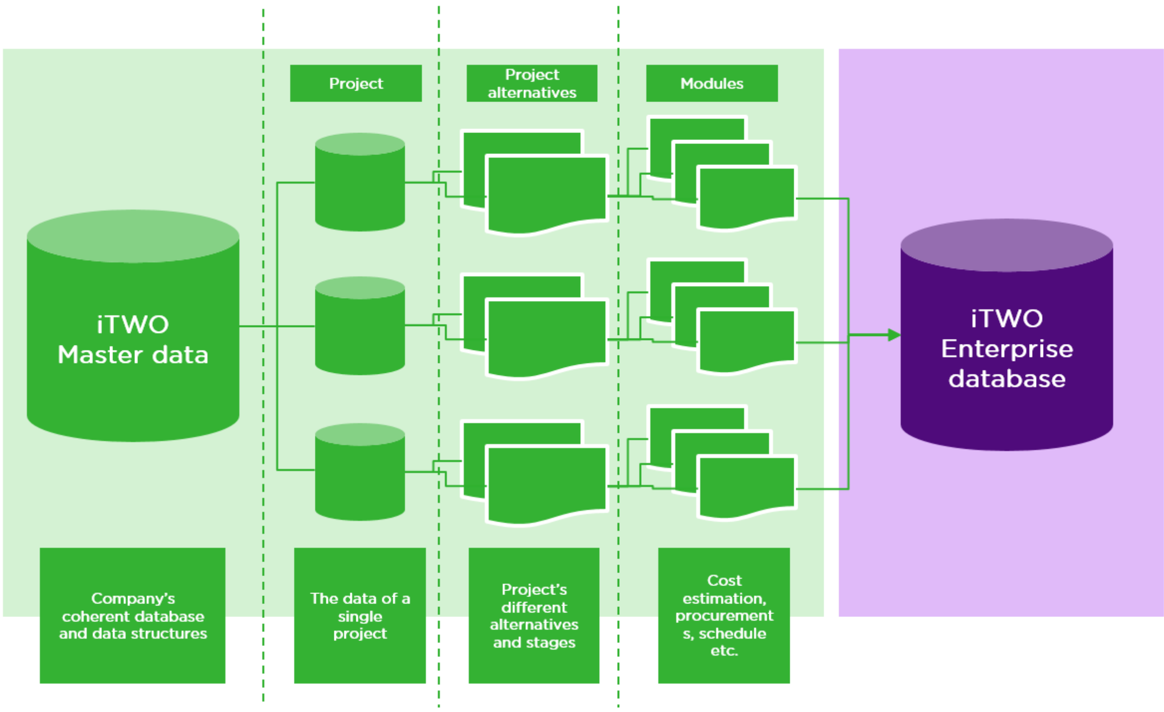


Figure 20. *Use of the databases in iTWO. (by courtesy of Fira Oy)*

5.2 Deciding a cost data model and workflows in iTWO

The RIB project participants had to evaluate the different options of the cost data model used in the future project. The company has been using the Talo 80 classification system, which is widely used in Finland. Talo 80 had been the base of the cost estimations and used on-site to manage invoices. It was admitted, that Talo 80 did not completely answer the needs of modern building projects and their cost controlling.

Another adequate option was the Talo 2000 classification. This classification is used in the Finnish BIM Standard and more information about the Talo 2000 can be found in chapter 2.3.2. Some of the participants were worried about changing the structure. They thought that there might be problems with the alteration and worried how the old cost data could be benefitted from. Human reluctance was another problem. The head of cost estimation team informed that they were willing to change the classification. Eventually the project participants mutually agreed on Talo 2000.

International classification systems were briefly discussed, but they were not an equal option to Talo classifications. The reasons for this are the lack of knowledge about other classifications and the easier change from Talo 80 to Talo 2000.

The case company decided on using the Talo 2000 project and production classifications with some changes. The project classification will be used as the main classification, but the production classification is used for procurements as a work item catalog number. There was a debate on the need of two classification systems used together, but currently it seems that this can be made possible. The disadvantages and advantages of two classifications used together are presented in Table 12.

Table 12. *Advantages and disadvantages of two classification system used together.*

Advantages	Disadvantages
Tracking cost of materials under one contract is easier	Invoices must be assigned to two cost control units which adds human error and workload
Subcontract management is easier and gives more data about additional work	The so-called hardware store purchases are hard to assign to two cost control units

The cost estimation done in iTWO required the cost codes of the company to be transferred manually to the application. After the cost codes were transferred, the work items could be created based on Talo 2000. An example of the product structure is presented in

Figure 21. Early cost estimations can be calculated using space objects. iTWO had problems reading these space objects and in some cases, it could not calculate the base area from them, even though Solibri could. This problem was with models created with Revit software. These cases were spaces with walls around them but with no floor object. Because iTWO calculates the base area from floors, the base area could not be calculated. Instead, Solibri uses the space object for the base area calculation and could present the area. Consults provided means for calculating the base area from these spaces. The case company also used Simplebim software for modifying models before entering them into iTWO. Simplebim had features better suited for the company's needs than iTWO's BIM Qualifier module.

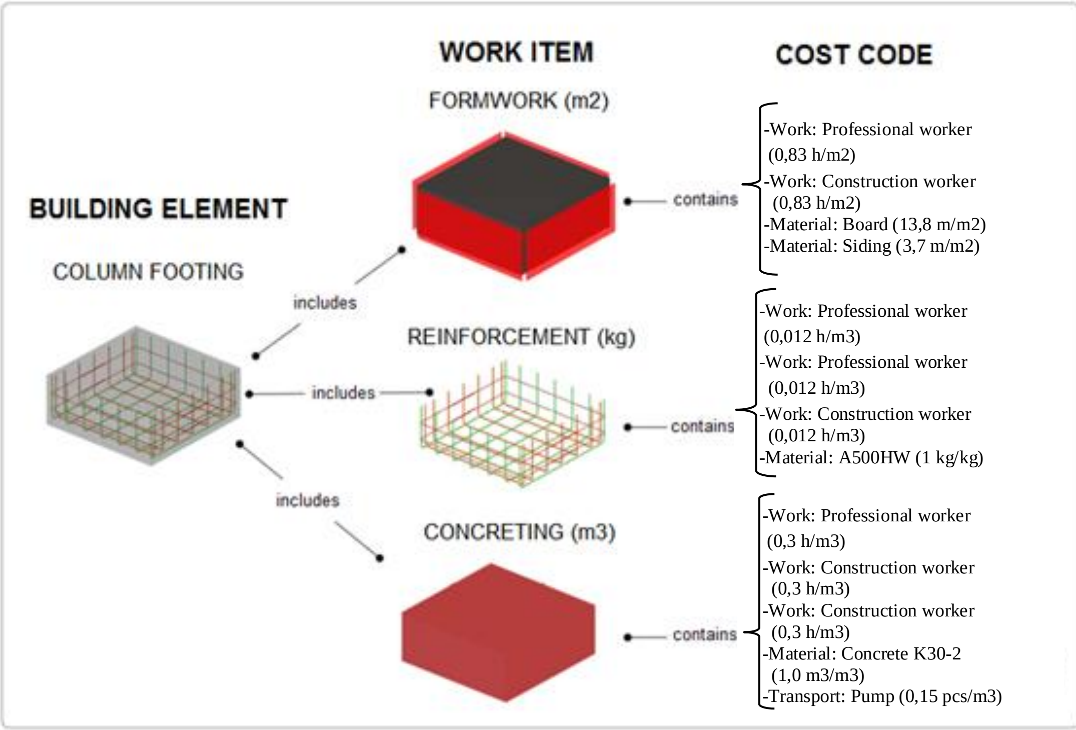


Figure 21. *Building product structure. (Translated from* (Teittinen 2009)*)*

iTWO has a module for scheduling called the Activity Model. It was noticed that the application was not as versatile as the company's present scheduling application. There is a development going on with a web-based iTWO 4.0 solution, which the case company decided to take into use beside the baseline version of iTWO. iTWO 4.0 gets information from the baseline version, but does not import the changes made in the 4.0 back to the baseline solution.

The data needed in iTWO had to be recognized because invoices are handled in a different system. The invoice has data on the project number, the invoicing company and the amount of money demanded. The person handling the invoice must add at least the cost code unit or units and the cost code type. There was a discussion with the project participants and RIB consultants about the workflow of invoicing. The consultants suggested that the invoices could be assigned in iTWO to prevent extra work. The problem with this was that the new workflow of invoice handling and the need for defining the invoices that should be handled through iTWO. If the invoices were just imported into iTWO, they would only be visible in the enterprise database instead of on a project level. An example of the invoicing workflows can be seen in Figures 22 and 23. It was decided that in the pilot projects invoices would not be handled through iTWO, but in the future, project invoicing could be partially done in iTWO.

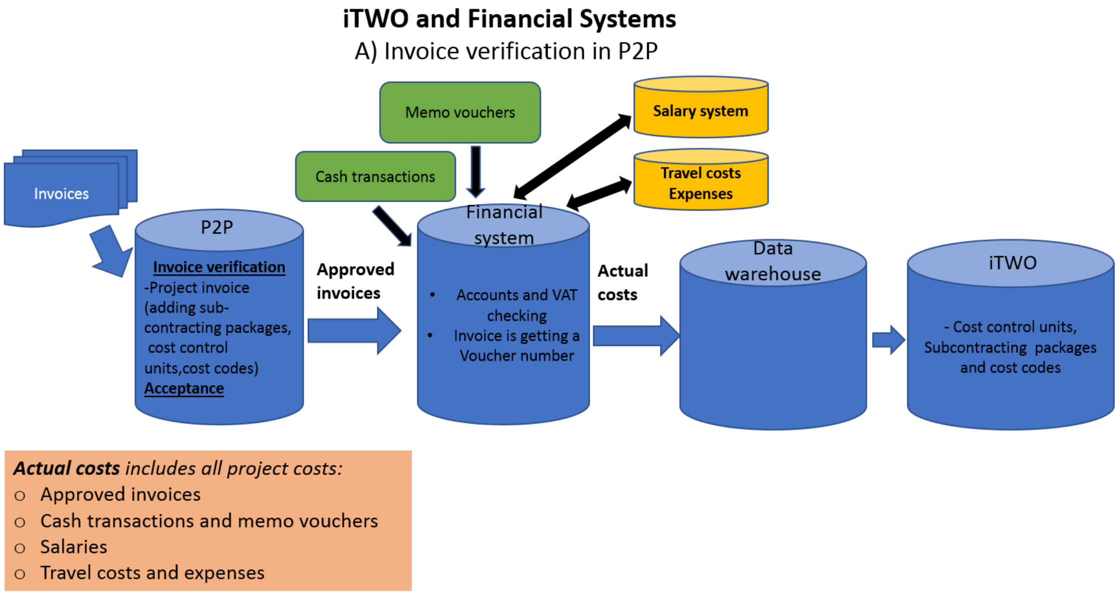


Figure 22. *Invoice verification option A. (By courtesy of Fira Oy)*

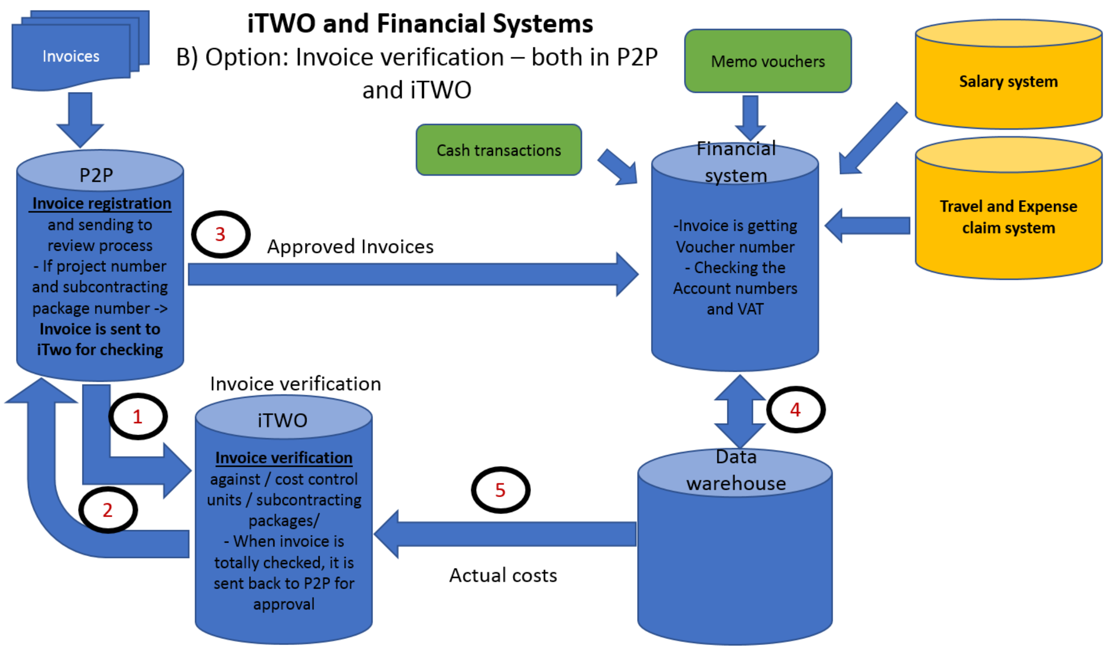


Figure 23. *Invoice verification option B. (By courtesy of Fira Oy)*

Subcontractor cost management can be done through subcontracting packages. iTWO enables the possibility for the main contractor to inform the subcontractor what to bill. Presently, the subcontractor charges the main contractor by mutually approved hours or installed quantities in the case company. It was decided that this process would be kept the same as before. Every project should have a procurement plan with information about the time and person responsible for the procurement. This was attempted to be done via iTWO, but there were problems scheduling the procurements. The company had a supplier register in excel format and thought of moving it to iTWO. There is a catalog called contacts in iTWO, in which the user can create a list of the suppliers. The suppliers can be linked to a certain work category, which was tested in the development project.

Construction projects have general and operating costs, such as the foremen's salary, the crane, the IT equipment, to mention a few. In the Talo 80 classification these were referred to as the 8-9 main groups. It was decided that these cost codes would be made into subcontracting packages to follow the costs in an efficient way.

The project data on the budget, the work scheduled and work done is imported to the enterprise database. It is possible to create forecasts through these imports but the import is not automatic. Instead, the person in charge; the site engineer for example, will do the reporting. The reporting periods are determined in the master data and are the same for all the projects. The company management should decide what financial information should be presented in these reports. It was decided that at least the same information as before should be reported. These reports were done with Excel sheets before iTWO but the case company was giving up the Excel-reporting. The current reported information is presented on Table 13.

Table 13. *Financial information reported in the case company before iTWO.*

Primary estimate of expenditures	Primary estimate of incomes	Primary estimate of cash flows
Revised estimate of expenditures	Revised estimate of incomes	Revised estimate of cash flows
Risk estimate minimum	Risk estimate probable	Risk estimate maximum
Opportunities estimate minimum	Opportunities estimate probable	Opportunities estimate maximum
Additional and change work offered	Additional and change work approved	Additional and change work invoiced

The primary estimates are done before the on-site work begins and do not change during the project. Revised estimates are updated monthly with the realized costs and forecasts. These estimates are currently based on the Talo 80 classification. Marginal profit can be calculated through the cumulative expenditures and revenues. Risk and opportunity estimates are quite specific and reasons for them to be realized are reported. The degree of completion will be reported in iTWO in addition to these.

Risk estimation was discussed without a clear decision. The company had a risks and opportunities report, but the concept of opportunities and probable risk was not clear. Opportunities could also be thought of as risks that do not occur and probable risk could be also seen as reserve. From discussions, an idea arose, that the subcontractor package prices could be thought of as committed cost that will occur in any case. Reserves are the probable risk and forecast the project's current situation. Risk minimum can also be an opportunity, because money is saved compared to the reserve. Risk maximum is the worst-case scenario of the project's expenditures. A possibility for risk management is presented in Figure 24.

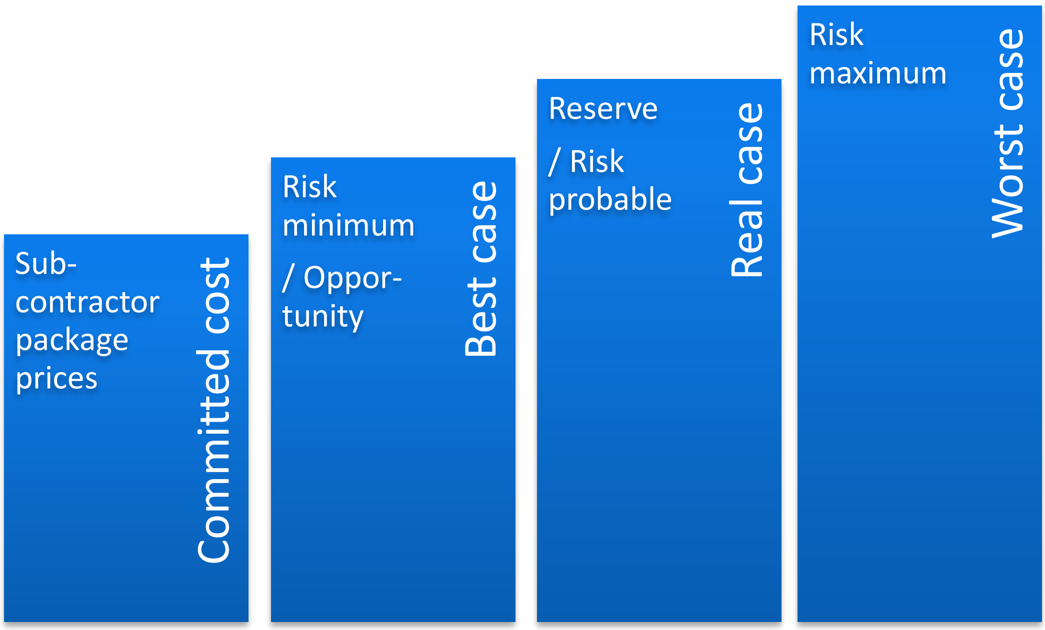


Figure 24. *A possibility for risk management*

Reporting is done through iTWO and these reports needed to be recognized. These were:

1. A controlling view of one project with key figures
2. Cross-projects controlling
3. Procurement reports, on project and company level with tasks and budgets
4. Schedules: procurement, design and general
5. Estimation reports with subgroups, profits and margins. Work items with cost codes and work categories must be also reported

6. Historical development with key figures

Key figures had not been yet decided, but at least SPI and CPI should be reported.

Using earned value analysis is possible in iTWO, but defining the values is ambiguous. As described in chapter 2.4.3. the basic values for EVM are ACWP, BCWP and BCWS. Tender estimate values could be used for budgeted cost for work performed and work scheduled but now the subcontractor prices are reported to controlling. A major problem is the actual cost of work performed. If the actual invoices from subcontractors are used, the payment occurs later than the work is performed, possibly in the next report period. Invoices usually have a minimum of two weeks' term of payment but it can be up to two months. Adjusted costs, accruals, could be used to estimate the actual cost of work performed. The billed quantity could be used instead of invoices. The billed quantity is inserted manually and can be based on the installed quantities. Hourly work or other additional costs could be added by accruals.

5.3 Workflow in iTWO

iTWO consists of modules used in different stages of a project. These modules work together, meaning that information created in one module is used also in the other modules. This chapter presents an example project created in iTWO to demonstrate the workflows. Different modules in iTWO can be seen in Figure 25. As mentioned before, this example involves only the light partition walls. Essential information is identified through the workflow to create a list for the project's development needs.

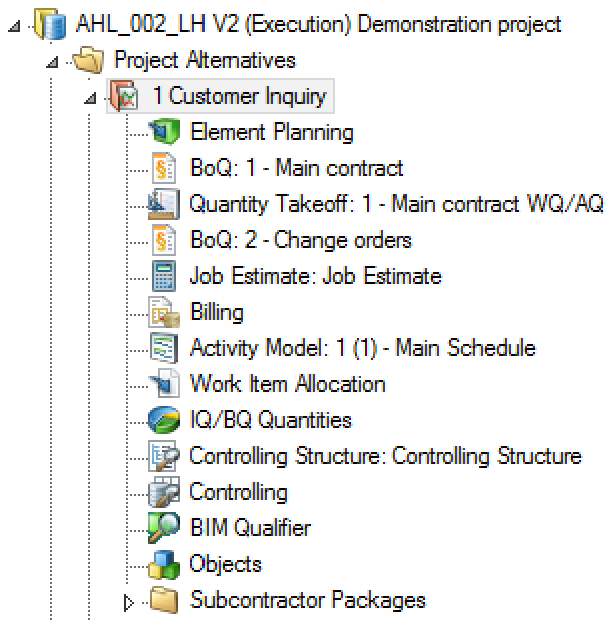


Figure 25. *Modules used in the application. (Screenshot from iTWO)*

5.3.1 Creating a new project

The user must define a project code and select the master project when creating a new project as presented in Figure 26. The project code is unique and cannot be used in other projects. The master project contains the basis of projects, such as the cost database, the schedule and the BoQ. The user can decide what information is transferred from the master to the new project and this can be done later in the project as well. The project needs be connected to the enterprise database for cross-project analysis. New alternatives of the project can be made inside it or the whole project can be copied into the project explorer.

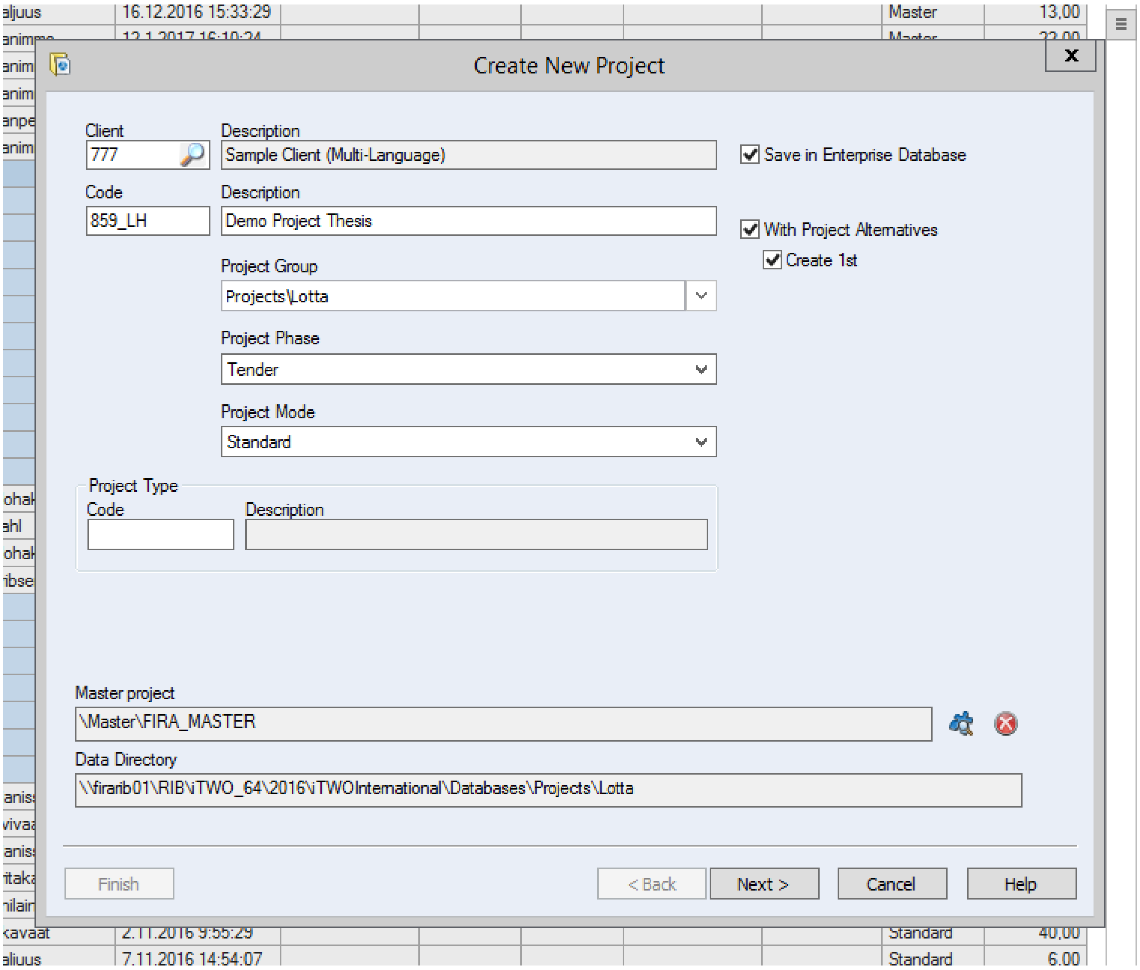


Figure 26. *Creating a new project. (Screenshot from iTWO)*

5.3.2 Importing IFC models

iTWO offers 3D-CAD-plugins for exporting 3D models. The case company decided on not using these plugins and the IFC models are imported instead. The module used for importing models is called the BIM Qualifier. The BIM Qualifier converts the model to CPI (Construction Process Integration) data, data type used by the application. The BIM Qualifier is also used for examining the model and making changes if needed. Heavy objects can be simplified in the CPI analyzer to make the model lighter to use. The case company also used Simplebim, as mentioned before. Once a model is imported to the BIM Qualifier, the following updated models should have the same name as the original. Objects can be grouped by using selection sets. Selection sets can use information fields of building information model to filter certain parts, types, heights, etcetera. The desktop view of BIM Qualifier is presented in Figure 27.

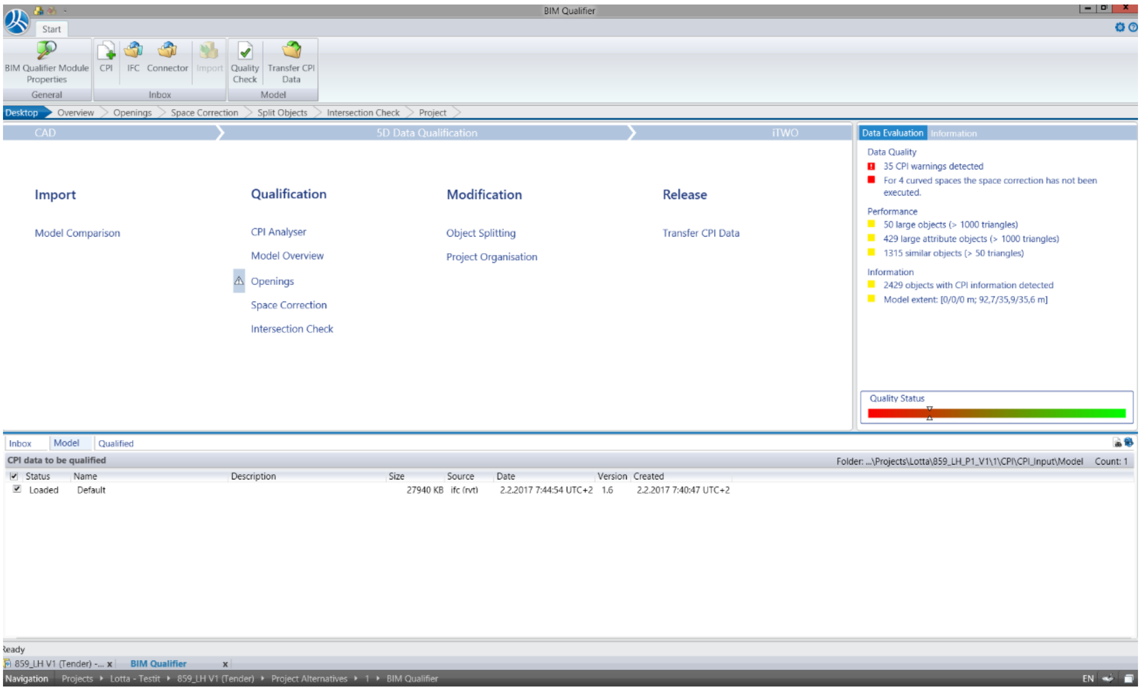


Figure 27. *BIM Qualifier desktop. (Screenshot form iTWO)*

5.3.3 Element Planning and estimates

BoQ is created model based, which means that the quantities are calculated from the objects in the model. iTWO enables multiple ways to calculate information from objects by using Quantity Take Off (QTO). An example of a QTO calculation is presented in Figure 28.

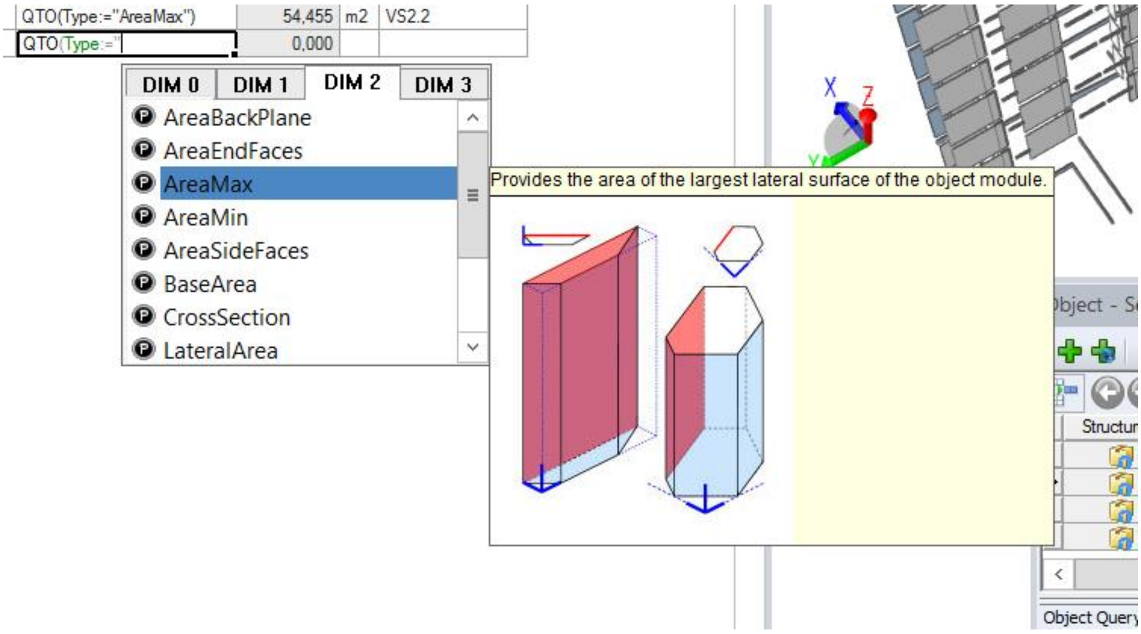


Figure 28. Example of a quantity take off. (Screenshot from iTWO)

Work items should be chosen from the master data's Work Item Catalog (WIC). The user can make a project-specific work items in the estimate, if the WIC does not have suitable items. A project-specific work item was created for to cover the flue and duct components in this case project. Other work items were slightly modified as per the original cost code structures. An example of the work item catalog is presented in Figure 29.

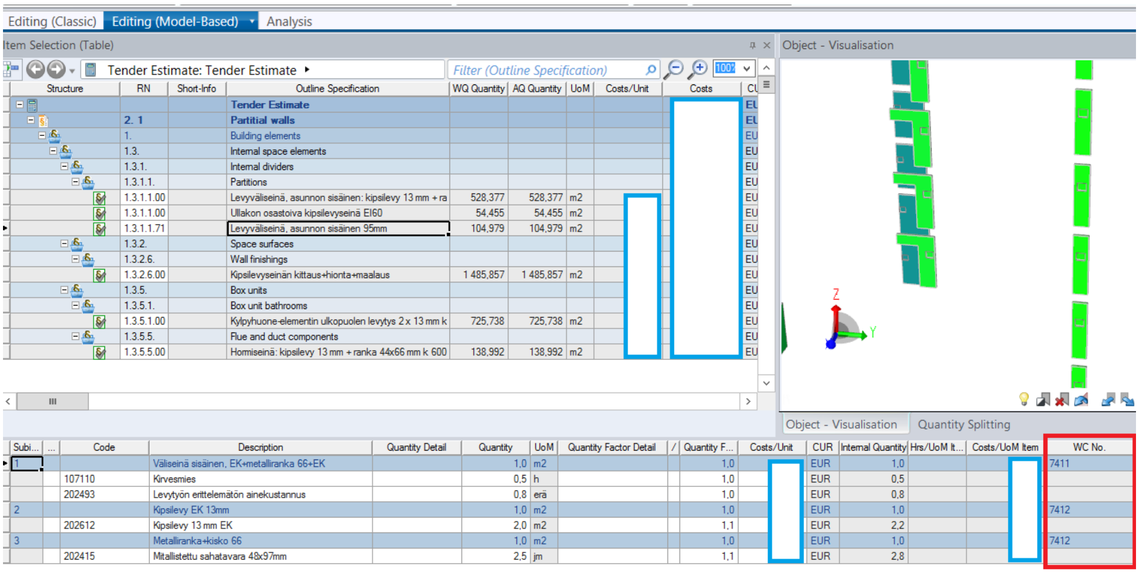


Figure 29. Project-specific work item added to the WIC. (Screenshot from iTWO)

Client's payments should be included in the project to create a cash flow forecast. This can be done by having a cost code for revenue and by creating a BoQ of these payments. The BoQ should be marked as revenue and this can only be done when the project is linked to the enterprise controlling.

5.3.4 Procurements

Subcontractor packages can be easily created in the work item allocation if the work items are allocated to work category numbers. These work category numbers were created according to the Talo 2000 Production classification with minor changes, presented in figure 30. Additional BoQ is created to every subcontracting package to add possible risks, revenues, additional work and change orders.

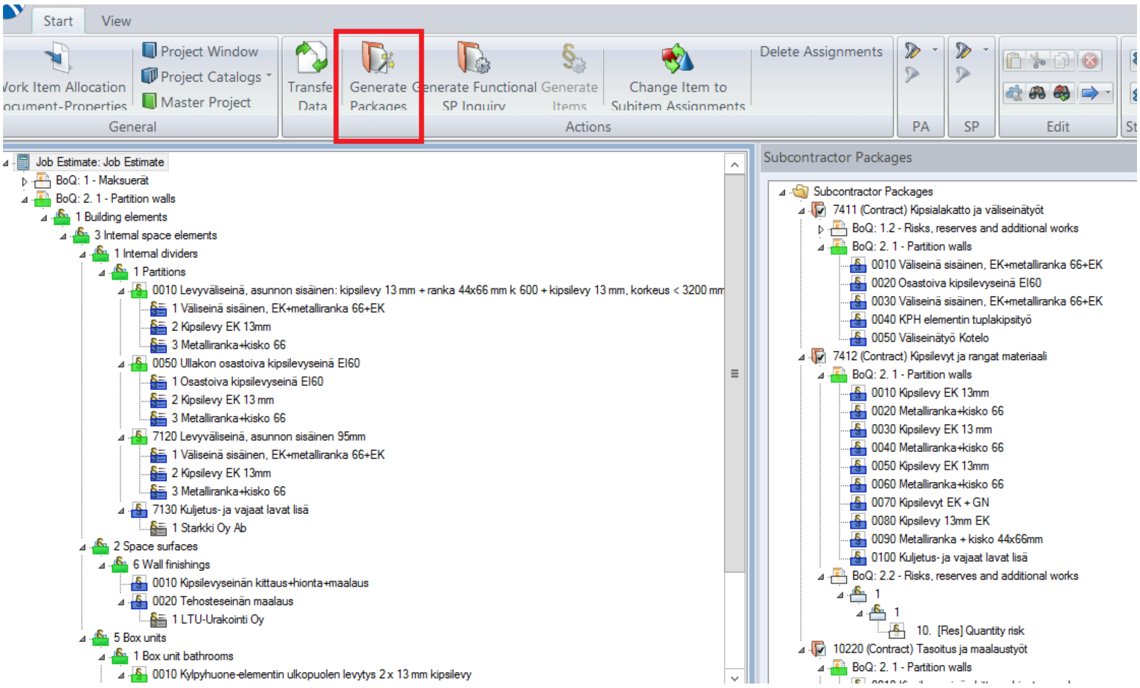


Figure 30. *Generating subcontractor packages according to work categories. (Screenshot from iTWO)*

Potential tenders can be chosen from the contacts catalog. Tenders have a Talo 2000 classification number depending on the work or materials they offer. Tendered prices can be input manually or if the tenders use iTWO's own platform, they can be imported directly Once the prices are input, they can be compared in iTWO to the estimate.

5.3.5 Scheduling

Scheduling is done in the Activity Model, presented in Figure 31. Activities are first created and objects or lines in BoQ are then allocated to them. Activities can be created separately for client's payments if necessary. It is easier to assign objects to activities, if the model is divided into segments and floors. Otherwise this can be done by percentages or by choosing those objects accomplished in certain activities. iTWO enables the creation of schedules by using hours, costs or quantities.

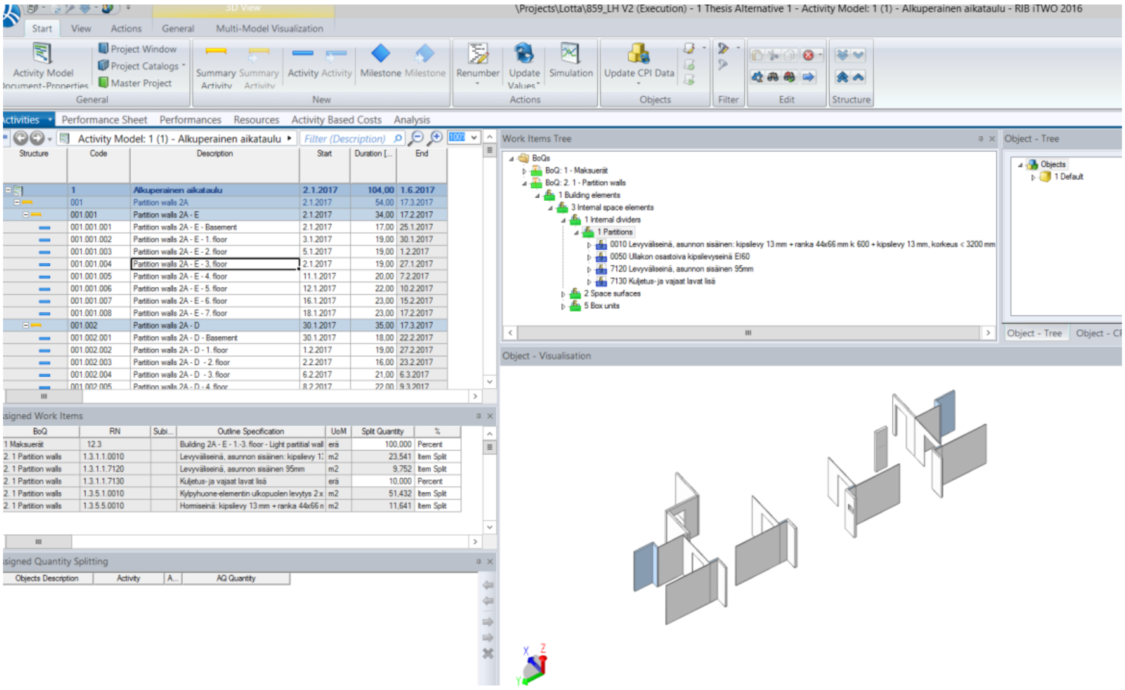


Figure 31. *Objects accomplished in an activity of partition walls. (Screenshot from iTWO)*

The desktop version of iTWO does not have the line of balance (LOB) schedule, but it can be created in the iTWO 4.0 solution. The building process can be simulated with costs and revenues by time as presented in Figure 32.

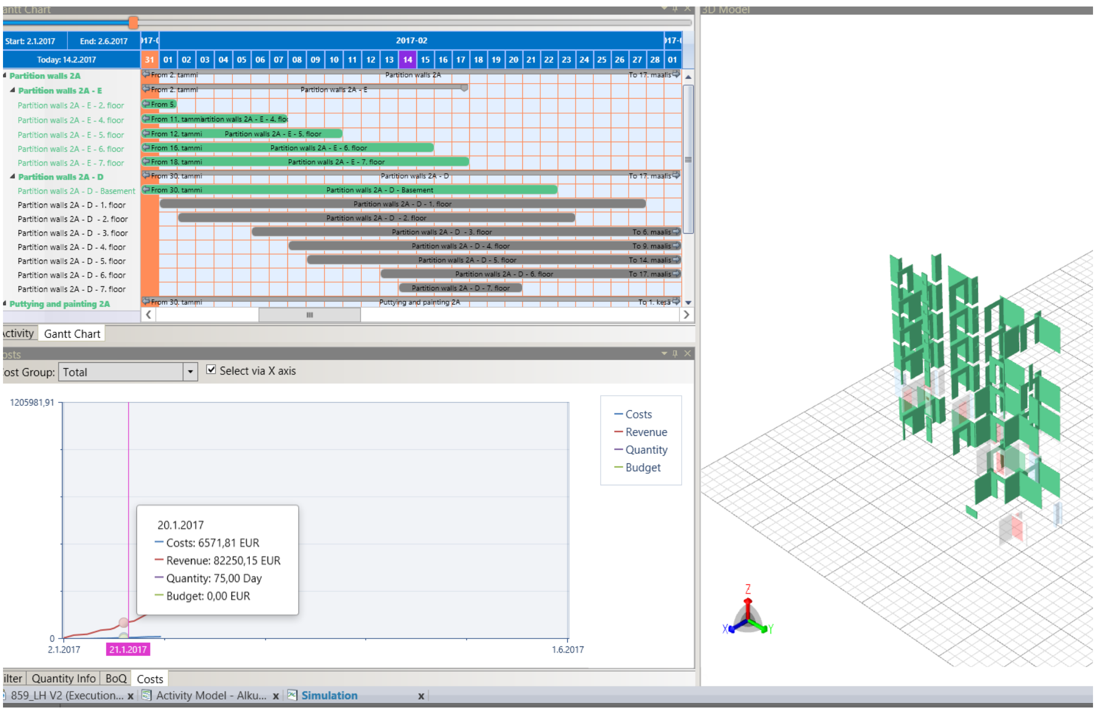


Figure 32. *Simulation of building process of partition walls. (Screenshot from iTWO)*

5.3.6 Execution

The project phase is changed to execution once the tendering phase is finished and a contract has been made. The execution phase has modules available only at this phase such as IQ/BQ, installed quantities, billed quantities, presented in Figure 33. The progress of the project is reported to iTWO by using IQ/BQ or the Activity model. Progress reporting can be done object-based or by percentage. iTWO uses the schedule information to present which objects are supposed to be installed in that report period. Progress can be also reported with a tablet on-site.

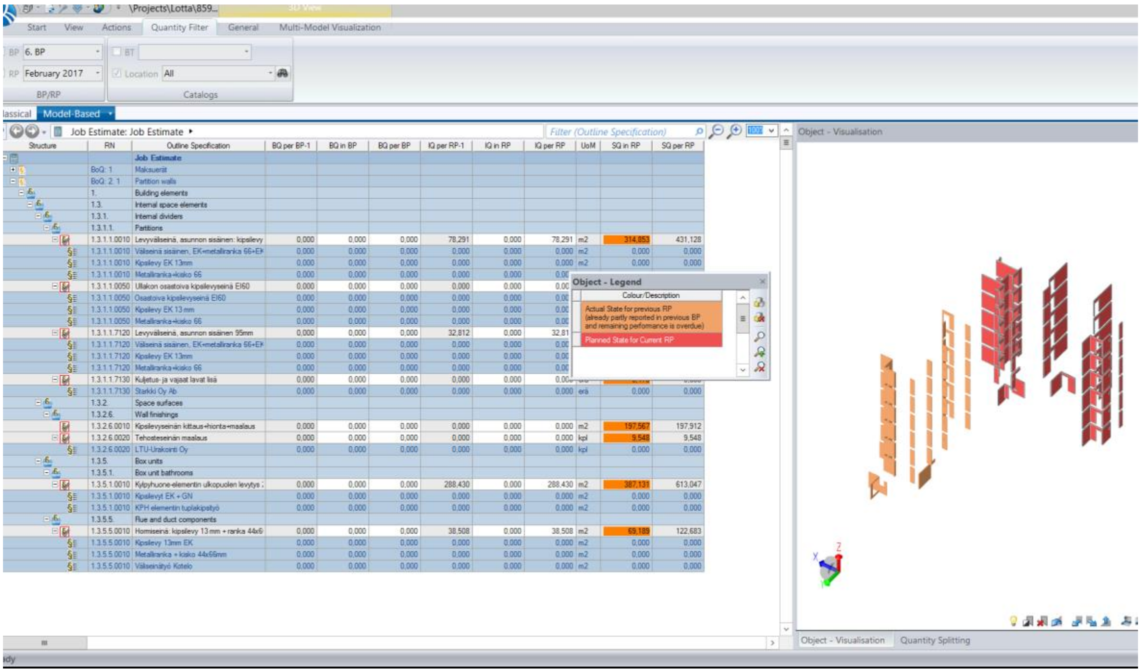


Figure 33. *Work to be completed by end of February. (Screenshot from iTWO)*

Invoice verification is performed in subcontracting packages. The amount of work is reported in BoQ's billed quantity (BQ) and they are automatically transferred to the invoice verification. Invoicing can be done by progress or by parts in lump sum contracts.

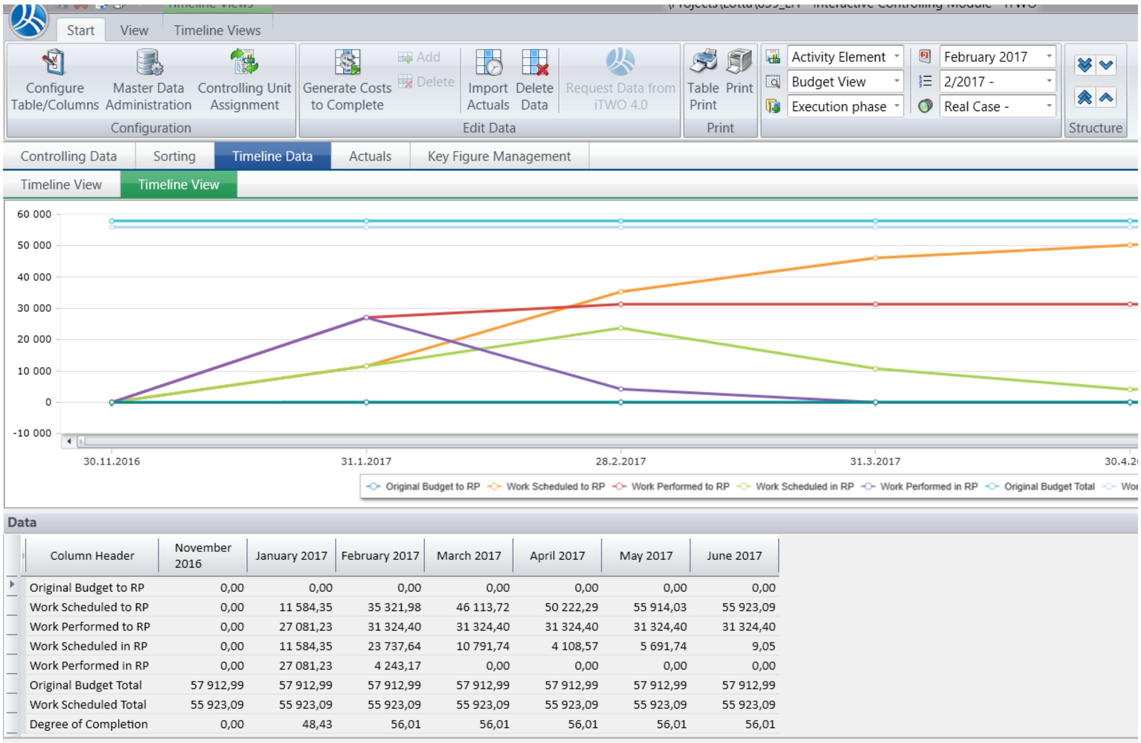
Subcontractor change orders are managed in subcontractor packages. A new change order is added into the Change Order Management and identified in the BoQ of the package.

Information about the project is reported to the enterprise controlling by the end of each report period. This information can be used by the management to be able to see the progress and state of the ongoing projects. Controlling structure, controlling cost codes and reporting periods must be same for all projects in enterprise controlling.

5.4 Financial analyses in iTWO

Financial analyses are performed in iTWO based on reported data from the projects. The Talo 80 classification had to be used as controlling structure because the case project was connected to the same enterprise database as the simulation project.

Analyses are done using controlling module. The imported data can be evaluated in different ways. The user must choose the report period and version of reporting under review. There are two views, budget and progress, which are chosen depending on the information needed. Imported data can be viewed with timeline data, presented in Figure 34.



Column Header	November 2016	January 2017	February 2017	March 2017	April 2017	May 2017	June 2017
Original Budget to RP	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Work Scheduled to RP	0,00	11 584,35	35 321,98	46 113,72	50 222,29	55 914,03	55 923,09
Work Performed to RP	0,00	27 081,23	31 324,40	31 324,40	31 324,40	31 324,40	31 324,40
Work Scheduled in RP	0,00	11 584,35	23 737,64	10 791,74	4 108,57	5 691,74	9,05
Work Performed in RP	0,00	27 081,23	4 243,17	0,00	0,00	0,00	0,00
Original Budget Total	57 912,99	57 912,99	57 912,99	57 912,99	57 912,99	57 912,99	57 912,99
Work Scheduled Total	55 923,09	55 923,09	55 923,09	55 923,09	55 923,09	55 923,09	55 923,09
Degree of Completion	0,00	48,43	56,01	56,01	56,01	56,01	56,01

Figure 34. *Timeline data in a controlling module. (Screenshot from iTWO)*

iTWO can present the work scheduled and performed in and to the report period. These costs can be compared to see the status of the project. The degree of completion is presented as a percentage. The presentation of data is determined in the configuration and the main user determines the calculation methods.

The actuals must be reported to controlling, if the invoices are not verified in iTWO. This can be done by importing an excel file with the controlling classification code, cost code unit and invoice amount without taxes. Additional information can be imported to create more specific calculations.

Key figures can be examined in the controlling. Key figures had not been determined by the case company yet and therefore they were not examined. There are two kind of key figures: baseline and controlling.

Cross-project controlling is entered through iTWO desktop. Projects to be compared are chosen from a list which can be filtered. Projects must be connected to the same enterprise controlling and have the same report period. Cross-project controlling can be used on large projects that are divided into several projects in iTWO.

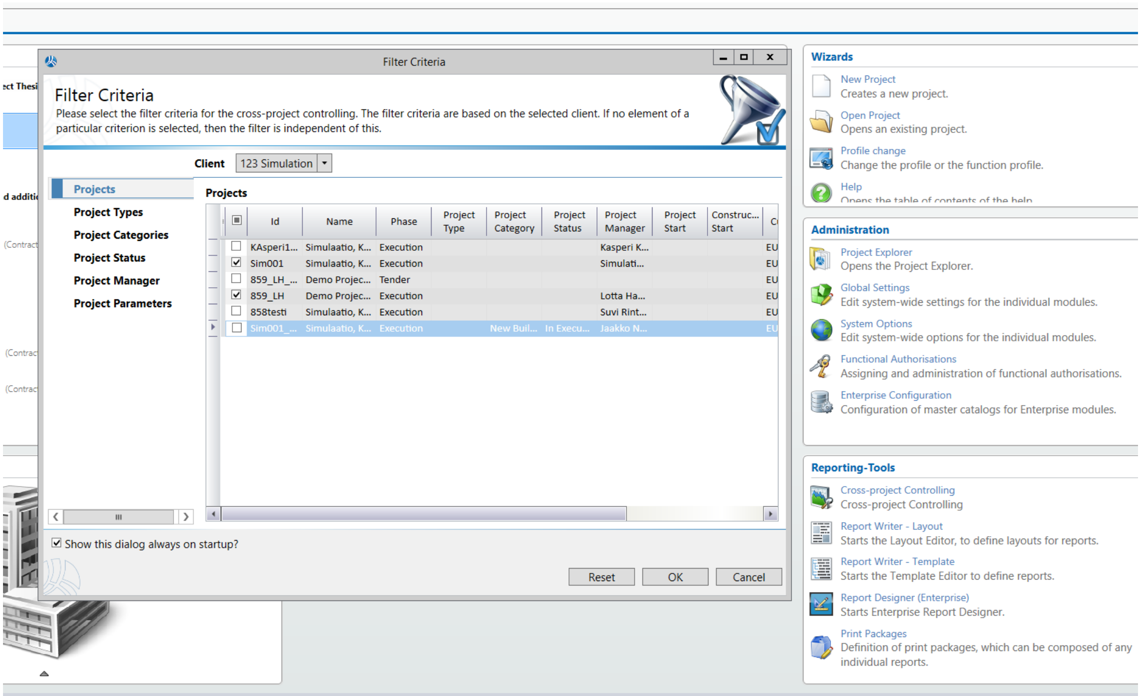


Figure 35. *Choosing projects for comparison. (Screenshot from iTWO)*

6. RESULTS AND ANALYSIS

This chapter includes the overview of the study, the results found and analysis. The research data used and gathered is explained in the overview of the study. The problems which occurred with the use of the cost data model and possible reports with the cost data model are presented. The use of the 5D BIM application is presented with problems and possibilities of the application.

6.1 Overview

The results of the empirical research are conducted in this chapter. The empirical research consisted of a development assignment and a demonstration of the chosen 5D BIM application. The main research data sources are presented in Appendixes C and D. The research data sources consisted of two OneNote files, a shared folder, a questionnaire and several project meetings. The internal company folder, a shared folder, a project bank and the cost controlling software were used as the research data source in the demonstration. The cost estimation with the work items was provided by the case study's site engineer.

The research data gathered in the research included decisions made in the development project and workflows. The demonstration was conducted based on these decisions to test out how the iTWO application works on an actual project's light partition walls. The research data gathered in the case study included the information needed to conduct the study, the usage of the application and problems occurring during the usage.

6.2 Cost data classification and analysis

The Talo 2000 classification was used as the basis of the cost data model, but the original cost estimation was calculated with the Talo 80 classification. Cost management and reporting tools are presented in this chapter. There were two main complications found in this study regarding cost management and these were cost estimation accuracy and design information accuracy.

The allocation of cost data, by Talo 2000 classification in iTWO, is presented in Figures 36, 37 and 38. The Talo 2000 Project classification is used for creating the BoQ. The BoQ contains work items, which contain cost codes. Controlling structure and procurement packages are used for cost control. The subcontractor invoices are given information about their cost control unit, cost code type and subcontracting package. Some of the invoices might not have the subcontracting package. The work items are also scheduled, which gives them the time dimension. This time dimension is also imported to cost control.

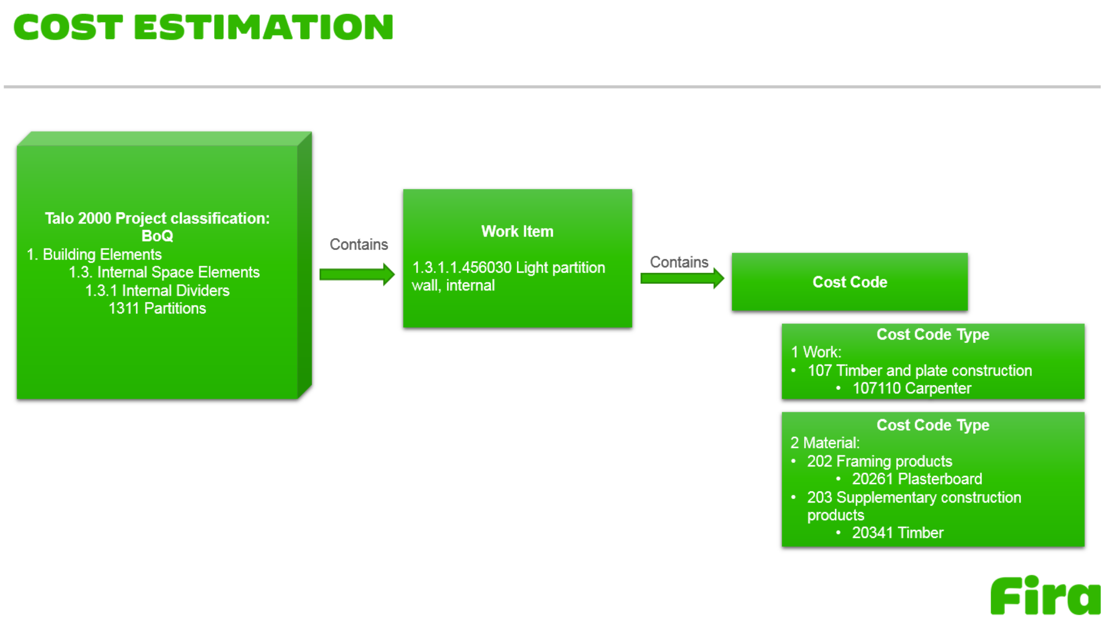


Figure 36. *Creating a cost estimation of a partition wall.*

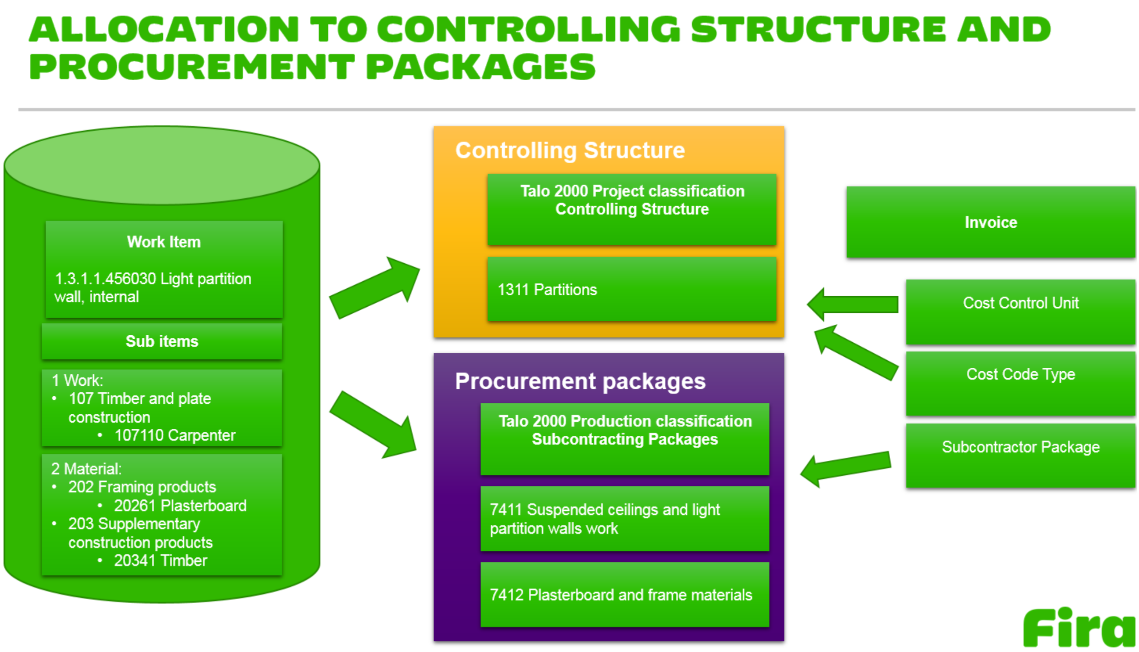


Figure 37. *Allocating the cost data information to controlling structure and procurements packages.*

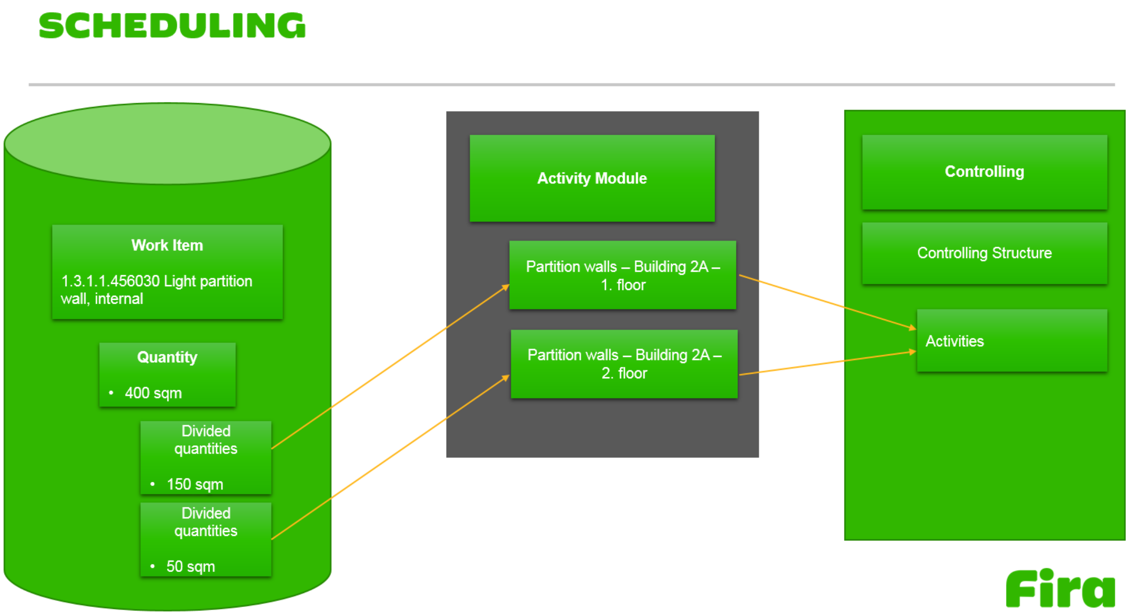
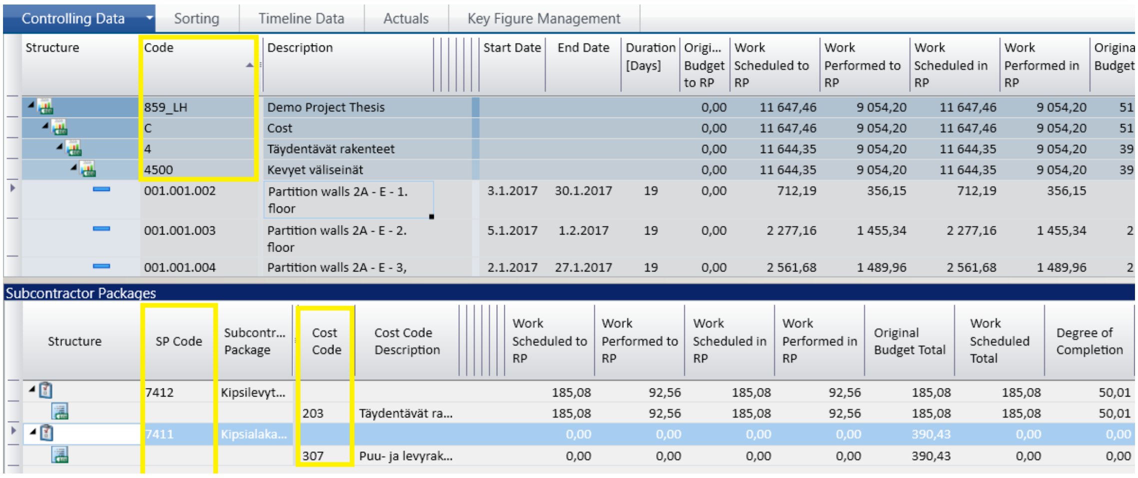


Figure 38. *Allocating the work items to activities, which are imported to the controlling module.*

6.2.1 Cost management and reporting tools

Costs can be viewed in control by the second lowest level, lower cost code type, presented in Figure 39. The controlling structure is now using the Talo 80 classification, but will be updated to Talo 2000 later. The subcontractor package (SP) code is using modified Talo 2000 Production classification and the cost codes are the company’s own, even though the first number is by commonly used type numbers and also a part of Talo 2000. Costs can also be viewed by activities. These costs can be compared to the scheduled costs and the module calculates the degree of completion.



Controlling Data | Sorting | Timeline Data | Actuals | Key Figure Management

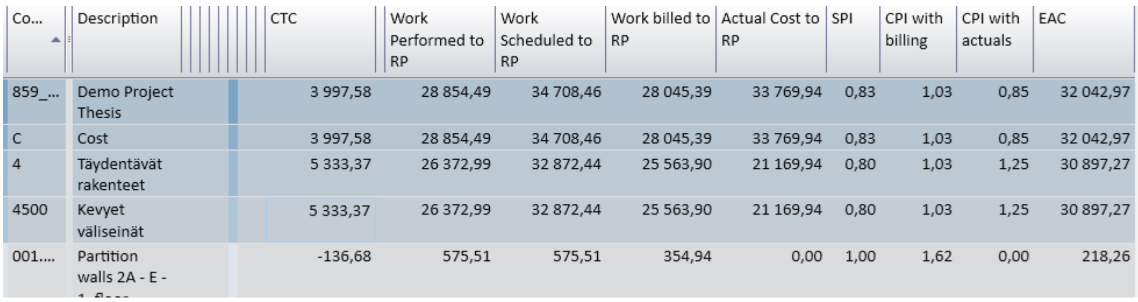
Structure	Code	Description	Start Date	End Date	Duration [Days]	Origi... Budget to RP	Work Scheduled to RP	Work Performed to RP	Work Scheduled in RP	Work Performed in RP	Origina Budget
	859_LH	Demo Project Thesis				0,00	11 647,46	9 054,20	11 647,46	9 054,20	51
	C	Cost				0,00	11 647,46	9 054,20	11 647,46	9 054,20	51
	4	Täydentävät rakenteet				0,00	11 644,35	9 054,20	11 644,35	9 054,20	39
	4500	Kevyet väliseinät				0,00	11 644,35	9 054,20	11 644,35	9 054,20	39
	001.001.002	Partition walls 2A - E - 1. floor	3.1.2017	30.1.2017	19	0,00	712,19	356,15	712,19	356,15	
	001.001.003	Partition walls 2A - E - 2. floor	5.1.2017	1.2.2017	19	0,00	2 277,16	1 455,34	2 277,16	1 455,34	2
	001.001.004	Partition walls 2A - E - 3,	2.1.2017	27.1.2017	19	0,00	2 561,68	1 489,96	2 561,68	1 489,96	2

Subcontractor Packages

Structure	SP Code	Subcontr... Package	Cost Code	Cost Code Description	Work Scheduled to RP	Work Performed to RP	Work Scheduled in RP	Work Performed in RP	Original Budget Total	Work Scheduled Total	Degree of Completion
	7412	Kipsilevyt...			185,08	92,56	185,08	92,56	185,08	185,08	50,01
			203	Täydentävät ra...	185,08	92,56	185,08	92,56	185,08	185,08	50,01
	7411	Kipsialaka...			0,00	0,00	0,00	0,00	390,43	0,00	0,00
			307	Puu- ja levyrak...	0,00	0,00	0,00	0,00	390,43	0,00	0,00

Figure 39. *Costs can be viewed by controlling structure code, subcontractor package code and cost code.*

The master data views were configured to create earned value analysis. A new view called cost to complete was created and columns were added to it. These columns are presented in Figure 40. There are two different CPI columns. CPI with billing is based on the costs defined in the subcontractor invoice verification and are coming from the installed quantities. CPI with actuals is based on the actual invoices handled during the demonstration and they are imported into iTWO. It can be conducted from the figure that the project's partition walls are behind schedule, but there are no cost overruns. When comparing the CPI with billing and CPI with actuals, we can see the need for using corrected cost. If the projects use only the CPI with actuals, they might have too optimistic view of the CPI, until all the invoices are handled.



Co...	Description	CTC	Work Performed to RP	Work Scheduled to RP	Work billed to RP	Actual Cost to RP	SPI	CPI with billing	CPI with actuals	EAC
859_...	Demo Project Thesis	3 997,58	28 854,49	34 708,46	28 045,39	33 769,94	0,83	1,03	0,85	32 042,97
C	Cost	3 997,58	28 854,49	34 708,46	28 045,39	33 769,94	0,83	1,03	0,85	32 042,97
4	Täydentävät rakenteet	5 333,37	26 372,99	32 872,44	25 563,90	21 169,94	0,80	1,03	1,25	30 897,27
4500	Kevyet väliseinät	5 333,37	26 372,99	32 872,44	25 563,90	21 169,94	0,80	1,03	1,25	30 897,27
001....	Partition walls 2A - E -	-136,68	575,51	575,51	354,94	0,00	1,00	1,62	0,00	218,26

Figure 40. *Earned value analysis in iTWO.*

The cash flow forecast can be checked in the activity model. This does not take into account the gap between work done and the invoice being paid and shows the whole situation of the project, presented in Figure 41.

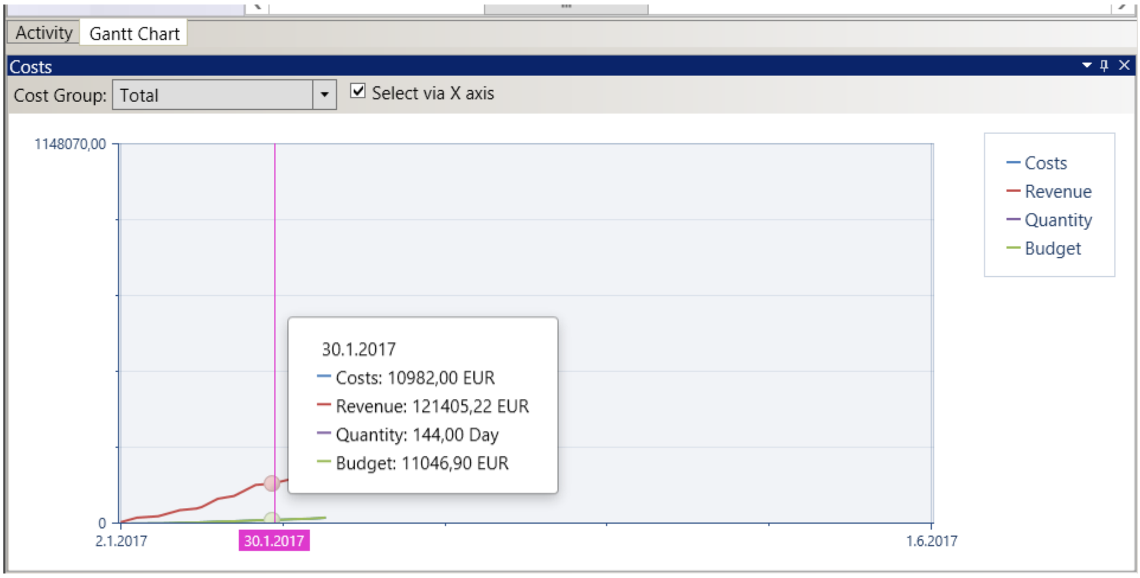


Figure 41. *Cash flow forecast in an activity model. (Screenshot from iTWO)*

A more accurate report can be printed as well, where the cash outflows are by work item cost classification and cash inflows come from the payment plan. The payment dates come from billing and invoice documents, which means they are based on the actual payment dates. An example of the report is presented in Figure 42. This report is not suitable for forecasting, but for later comparison.

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Comparison Cash inflow / Cash flow

Date	Activity	Cash inflow Net in EUR	Cash Outflow Net in EUR	Cash inflow cum. in EUR	Cash Outflow cum. in EUR	Difference in EUR
31.10.2016	7412 Kipsilevyt ja rangat materiaali Kipsilevyt ja rangat materiaali		[redacted]			
	Total 10.2016		[redacted]		[redacted]	[redacted]
25.11.2016	7412 Kipsilevyt ja rangat materiaali Kipsilevyt ja rangat materiaali		[redacted]			
	Total 11.2016		[redacted]		[redacted]	[redacted]
19.12.2016	7412 Kipsilevyt ja rangat materiaali Kipsilevyt ja rangat materiaali		[redacted]			
27.12.2016	7412 Kipsilevyt ja rangat materiaali Kipsilevyt ja rangat materiaali		[redacted]			
	Total 12.2016		[redacted]		[redacted]	[redacted]
27.2.2017	1 Thesis Alternative 1 Thesis Alternative 1	[redacted]				
27.2.2017	1 Thesis Alternative 1 Thesis Alternative 1	[redacted]				
27.2.2017	10220 Tasoitus ja maalaustyöt Tasoitus ja maalaustyöt		[redacted]			
1.2.2017	7411 Kipsialakatto ja väliseinätyöt Kipsialakatto ja väliseinätyöt		[redacted]			
22.2.2017	7411 Kipsialakatto ja väliseinätyöt Kipsialakatto ja väliseinätyöt		[redacted]			
	Total 02.2017	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Figure 42. *Comparison report of cash inflow and outflow.*

6.2.2 Cost estimation accuracy

Cost estimates are done in different phases of the project and they become more accurate as the project progresses. The case company had a work item catalog which had the most usual work items used in estimates. These work items were structured using the Talo 2000 classification. The demonstration project brought out that these work items were not accurate enough for specific cost estimation. The partition work item catalog lacked all other stud spacing apart from 600 mm, even though the subcontractor offered prices for work through stud spacing of 300, 400 and 600 mm.

Another example was the puttying and painting of the partition walls, which was presented as one item without any sub items. It belonged to cost code three, which is the subcontracting with materials. This work item became problematic in scheduling. Because iTWO uses the BoQ as the basis of the schedule and the BoQ is based on the work items, this lead to puttying and painting being the same activity, even though they are separate kinds of work.

When comparing iTWO to the system used for cost controlling in the case company now, iTWO offers a more accurate way to control costs and overruns on-site. Invoices are compared to installed quantities so overruns are more easily detected, if the invoices are handled in iTWO. If the updated model shows higher quantities, the cost of this can be traced back to them.

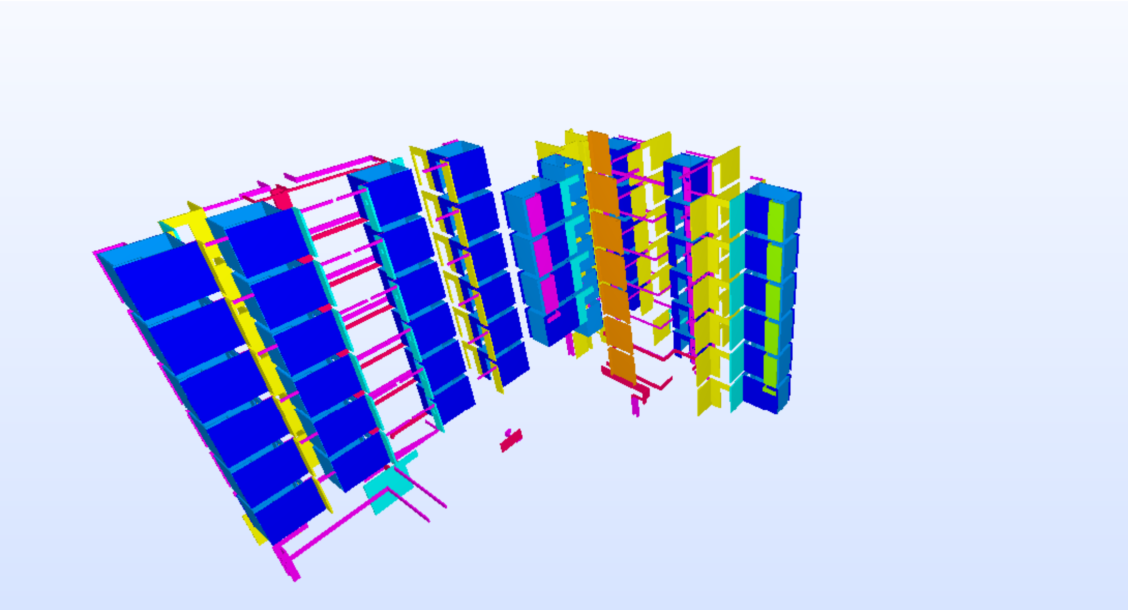
It must be understood that cost estimations must find the balance between accuracy and workload. Iterations of possible design alternatives demand multiple cost estimations, which should be done easily enough. In these cases, it would be best to update the work item catalog with new work items that could be used as the design becomes more accurate and changes are not as dramatic. Collaboration is needed between cost estimators, designers and purchasing engineers to define the accuracy of information.

6.2.3 Design information accuracy

Only the architectural model was used in this research, but it was found that it had problems with information management. The structural designers had created the structural element types document, which presented basic partition walls as VS2 and flue covering in apartments as VS8. The architect had used the following light partition wall types:

- VS2 – Light partition wall
- VS2.1 – Light partition wall, casing
- VS2.1 – Light partition wall, covering
- VS2.2– Light partition wall, casing EI60
- VS2.3 – Light partition wall, 95
- VS2.5 – Light partition wall, casing EI30
- VS8 – Light partition wall, casing

These walls also had differing information between code and type fields of non-bearing partition walls, presented in Figure 43.



Information Takeoff | Takeoff Selected

Component	Partition walls, non-bearing.Code	Type	Partition walls, non-bearing.Type	Area	Color
Wall	VS2	VS2 - Kevyt väliseinä	Basic Wall: VS2 - Kevyt väliseinä	423.41 m2	
Wall	VS2	VS2.3 - Kevyt väliseinä, 95	Basic Wall: VS2.3 - Kevyt väliseinä, 95	104.98 m2	
Wall	VS2.1	VS2.1 - Kevyt levyväliseinä, kotelo	Basic Wall: VS2.1 - Kevyt levyväliseinä, kotelo	184.65 m2	
Wall	VS2.1	VS2.1 - Kevyt levyväliseinä, verhous	Basic Wall: VS2.1 - Kevyt levyväliseinä, verhous	725.71 m2	
Wall	VS2.2	VS2.2 - Kevyt levyväliseinä, kotelo EI60	Basic Wall: VS2.2 - Kevyt levyväliseinä, kotelo EI60	54.46 m2	
Wall	VS2.5	VS2.5 - Kevyt levyväliseinä, kotelo EI30	Basic Wall: VS2.5 - Kevyt levyväliseinä, kotelo EI30	65.35 m2	
Wall	VS7	VS8 - Elementtikylpyhuoneen seinä	Basic Wall: VS8 - Elementtikylpyhuoneen seinä	1,081.90 m2	
Wall	VS8	VS8 - Kevyt levyväliseinä, kotelo	Basic Wall: VS8 - Kevyt levyväliseinä, kotelo	18.87 m2	

Figure 43. *Light partition walls information fields. (Screenshot from Solibri)*

These information fields could become problematic, if the code field was used for selection sets in iTWO, for example. The light partition walls also included objects that should be calculated as part of the suspended ceiling.

The procurement had not included casing in the light partition walls work. These were calculated at the price of suspended ceilings, which is measured by square meters, whereas casing is measured by running meters. This was probably because the suspended ceiling objects in the model were not marked as casing.

6.3 Use of 5D BIM

The possibilities and problems in the use of 5D BIM have been gathered by the results of the case study and by a questionnaire sent to the iTWO development projects core team. The results of the case study are presented in Table 14 and the results of the questionnaire are combined in Table 15. The tables are divided by iTWO's modules and the combination of modules, such as procurement and execution. iTWO's workflow is presented in the case study. 5D BIM is considered as the iTWO application in this research. The case study included only an architectural model and light partition walls which made it lighter to do than an actual project. Still there were performance issues with iTWO. The case study also reflects on the problems that the case company might have with their current way of working, for example the accuracy of the tender estimates.

We can see from Table 14 that in some cases iTWO does not offer as good properties as the case company's previous system and the case company must update their work items and selection sets. iTWO enables automatization in element planning and procurements which can ease out the work. Progress reporting will also be more accurate but this means that the controlling part must be configured and invoices must be imported to iTWO.

Table 14. *Case study's result of use of 5D BIM a. and b.*

Results of the case study			
a.	**BIM Qualifier**	**Element Planning**	**Tender/Job Estimate**
Possibilities	Changes in the model can be identified	Model based quantity take-offs	Possibility to use master data or project-specific work items
	Large objects can be simplified in CPI analyzer	Automatization with selection sets	
Problems	Model update had errors when the name of the model was changed but the model remained same	Company's current selection sets were not accurate enough	Some of the company's work items were not detailed enough to create the general schedule
	The architect's model needed refining in Simplebim		
	Importing architectural model took over 5 minutes		

Results of the case study				
b.	**Procurement**	**Scheduling**	**Execution**	**Controlling**
Possibilities	Subcontractor packages can be automatically created through work category number.	Visualization of the schedule with the model.	Progress reporting is more accurate.	It is possible to use earned value analysis.
Problems	An additional BoQ for risk, change and additional work must be created.	Lack of LOB scheduling. Available with iTWO 4.0	Model updates take time and update frequency must be decided on.	Configurations are complicated to do.
		The current scheduling application is more versatile.	Invoice information only at enterprise controlling. The workload increases if done in iTWO.	
			Risk/reserve management of the case company still in progress in iTWO.	

The Table 15 presents a wider description of the possibilities and problems in iTWO. The most problematic modules were the BIM Qualifier and scheduling. Other applications were considered better than the these. The execution combination of modules had problems and it was pointed out that it seems that application is created from the estimation point-of-view and using iTWO during execution takes a lot of time. Element Planning and procurement was considered quite good and both could be automated to some extent. Most of the modules or combinations of modules were considered versatile or complicated.

Table 15. *Results of the questionnaire (a. and b.).*

Results of the questionnaire			
a.	**BIM Qualifier**	**Element Planning**	**Tender Estimate**
Possibilities	CPI Analyzer finds the errors in geometry well and they are easy to fix. The models are examined from estimations point of view. Precise analysis and explicit workflow built-in.	Extremely versatile quantity take-off platform with dynamic selection sets. Possibility to use templates. The model is visible and estimation rules can be extensively defined. The allocation of quantities can be automated quite far and updating the estimation is more automatic.	Relatively easy to create new work items and estimates. Logical and diverse tool. Comparable and updatable data from master project.
Problems	There are other tools better suited for modifying the model. There seems to be a lack of clear logic of what, when and which objects can be fixed. Adding attribute information is clumsy.	Unnecessarily complicate. Performance issues with selection sets and generally with large models. Modifying a set of quantity take-off formulas is almost impossible without going through them individually.	Quite complicated if compared to the previous system.

Results of the questionnaire				
b.	**Procurement**	**Scheduling**	**Execution**	**Controlling**
Possibilities	Creating subcontractor packages is automatic and logical. Administering procurements is much better than before. Follow-up and reporting are overwhelming compared to the current system.	Schedules can be imported. Linking the schedule to costs is quite easy. Entering the realization is visual and quite easy. It is possible to visualize the schedule with the model. iTWO 4.0 seems promising. Good for modeling the cash flows. The schedule has a link to quantities and costs.	A detailed view of the job estimate and bill of quantities. Many of the information fields can be made visual when needed. Creating reserves is possible and creating additional and/or change orders is logical. Entering realizations and inspecting them can be done in more than one way.	Data can be checked from different points of view and the views can be modified by needs. SQL-database enables a transparent way to share information forwards. Might not be the easiest to use, but with the right configurations it is possible to get the right information with few clicks.
Problems	Feels complicated.	The activity module is not really meant for planning the schedule. Visual presentation of the schedule.	Takes a lot of time. The role of execution demands very diverse understanding of the system and its cause-and-effect relations. Subcontractor packages view could be better in means of status and data fields to be shown. The application is created from an estimation's point-of-view and it is questionable if it creates any additional value for execution.	Could be more illustrative and has a lot to be configured. Controlling does not have a link to the model so model based analyzes must be done in the baseline.

The questionnaire also included grading for different parts of iTWO and iTWO in general. The overall grades are presented in Figure 44. The overall grades are equivalent to the verbal answers. Highest scores were given to the Tender/Job Estimate, procurement and controlling. The BIM Qualifier and scheduling had the biggest problems and other applications might be used beside these.

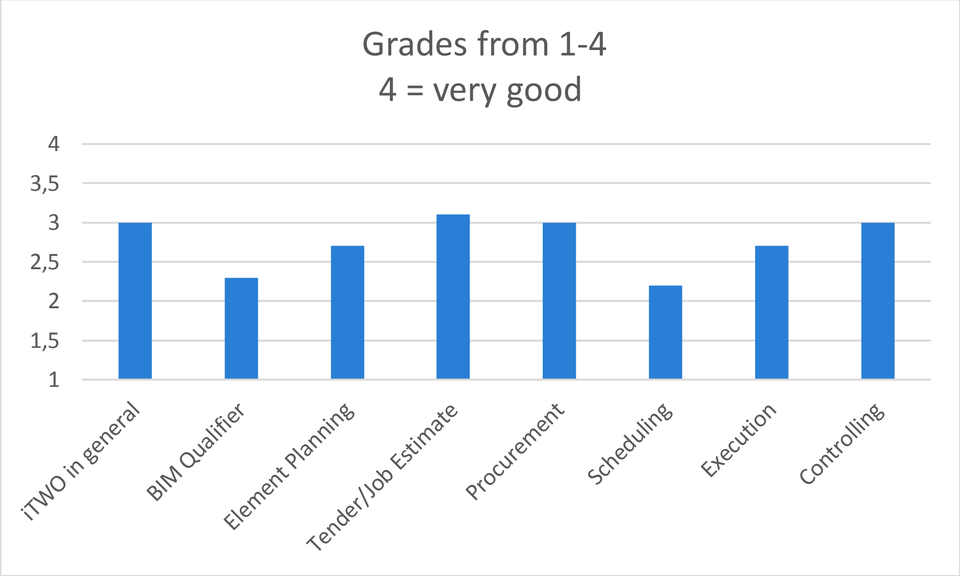


Figure 44. *Grades for modules or combination of modules in iTWO.*

The questionnaire included statements about iTWO, that the subjects could choose from or add a statement of their own. Two participants had other statements and these were the following: "*The reliability of the information is dependent on the reliability of the information source (building information models) and the methodicalness of the users*" and "*iTWO is necessary because the system makes people justify and explain their work better (by built-in functions)*". Both statements have been translated from Finnish.

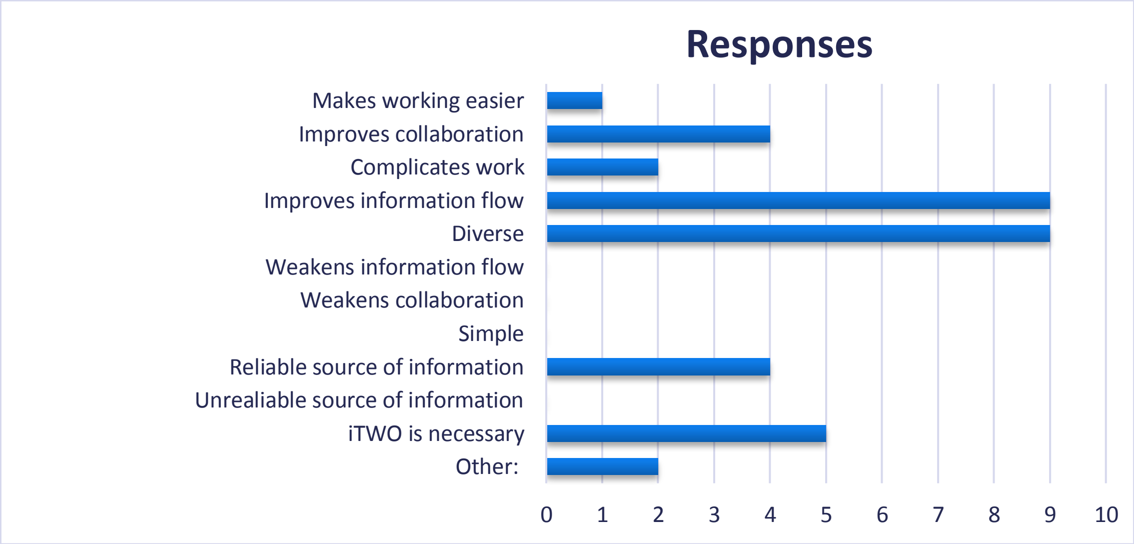


Figure 45. *Statements about iTWO.*

It can be conducted from these results of the case study and the questionnaire that the usage of 5D BIM is good and project participants are quite content with iTWO. Most of the modules were graded almost or good and iTWO in general was thought of as good. All the questionnaire subjects thought that iTWO improved information flow and almost half thought it was a reliable source of truth.

6.4 Gathering information

Research data needed to execute the case research was collected by the company's work phases: cost estimation, procurement, scheduling and execution and are presented in Table 16. Even though the design did not change during the case, the information gathered included multiple documents and different units. The use of iTWO helped the information to flow through the project.

Table 16. *Information needed through the case study (a. and b.)*

a.	**Cost Estimation**	**Procurement**
	Quantities: m^2 for partition walls and puttying and painting. **From:** Architectural model	**Quantities:** m^2 for partition walls and cubic content for puttying and painting. **From:** Architectural model, building project declaration
	Types: Different wall types. **From:** Architectural model or element types (information inadequate)	**Types:** Partition stud spacing, paint types and special walls. **From:** Element types, client's design manual
	Cost codes and work items from the master data	Potential subcontractors from contacts catalog

b.	**Scheduling**	**Execution**
	Quantities: Quantities with sections and floors. **From:** Architectural model	**Quantities:** Planned and actuals. **From:** Architectural model or drawings and measurement records
	Production rates from company's catalog and national production database	**Types:** Specific materials for CE and Declaration of Performance files. **From:** Procurement or client's design manual. CE and DoP files from manufacturers websites.
		Reinforcement panels placement from furniture drawings

7. DISCUSSION AND CONCLUSION

The research is evaluated in this chapter by presenting the objectives and how they were reached. The obtained results are presented by answering to the research questions presented in the beginning of this thesis. Recommendations and suggestions for research are presented.

7.1 Evaluation of the research

This research concentrated heavily on the use and implementation of one 5D BIM application. The results of this study can help the case company to concentrate on the problems found and solve them.

The main objective of this research was to have a cost data model for financial analyses. Different classifications were presented and the case company decided on the Talo 2000 classification. This classification was tested in the demonstration of the iTWO application. Cash flow forecast and earned value analyses were used and both could be presented.

The first milestone was the comparison between projects. This was not fully tested, because there were not enough data available to create a reliable comparison. The requirements for project comparison were defined. These are the same cost controlling structure, cost codes and report periods.

The second milestone was the transparency and continuity of the cost data model. The chosen classification was transparent and continuous throughout the project and the same data was used from cost estimation to execution.

The third milestone was the potentials of the 5D BIM application. The potentials and problems of the 5D BIM application were tested in the demonstration and a questionnaire was sent to the RIB project participants. The results were presented in an extensive table.

7.2 Obtained results

This chapter presents the results of this thesis and how the research questions were answered. There are also other obtained results beside these.

7.2.1 The research questions and answers

There were four research questions presented in the beginning of this thesis and these are answered in the following chapters.

What kind of classification serves information management?

This research presented a set of classification systems used in the construction industry. Some of them concentrated on the physical product of the construction by presenting them through work or products, such as the Talo 2000 classification, MasterFormat and UniFormat. OmniClass and Uniclass also stored related information, for example OmniClass Table 31 – Phases.

The Talo 2000 classification was chosen for the case study with the project and production classifications. The usage of the both, production and project classification together, made it easier to track the cost information of the materials and gave more information about the subcontractor’s additional work. The Talo 2000 serves as classification for cost data, but a more versatile classification is needed for additional information management.

How can Fira create a continuous, transparent cost data model that enables comparison inside and between projects?

The case company decided to use the Talo 2000 project and production classifications. Project’s costs can be viewed at the lower cost code type by using the classification with the iTWO application. Projects comparison is also possible with the application when the same controlling structure, cost codes and report periods are used in all projects.

What requirements does 5D BIM set on the cost data model?

5D BIM integrates the time and cost aspects to 3D BIM. Most of the costs are allocated to objects in the model, or at least the objects in the model are used to calculate the units of costs. There are also costs, that can’t be allocated to the model, such as scaffolding or general costs. The cost data model must have a cost control units for them.

The work items with the Talo 2000 classifications were allocated to the activities. The cost data model must be detailed enough for creating a general schedule and the work items should consist only of one work item.

What are those financial analyses that will be used to report the status of the projects?

The basic information about the projects is reported to the management, as before. These, and additional information used in EVM, can be used for financial analyses. These are the cash flow forecast, cost to complete, schedule performance index, cost performance index and estimation at completion.

7.3 Conclusion

The construction costs are determined in an early phase of the project, but they might change due to design detailing. The cost estimates can be calculated using multiple methods and there are several classifications available for structuring these estimates. Costs data should be monitored, recorded and analyzed.

There are several studies done on the benefits and barriers of 5D BIM. It can be conducted that 5D BIM is quite practical, but can create obstacles for non-BIM capable stakeholders. Implementing 5D BIM could help with data management and feedback was faster to design counterparts for cost planning purposes. 5D BIM with a cost classification system can bring more accurate information about estimated costs and costs occurring on-site. These costs can be viewed on a cost code level and forecasted with EVM. Because most of the costs are based on objects, quantity changes can be identified when the design model changes. The master data provides the same cost control structure and work items for all the projects, which means that they can be compared.

5D BIM can improve the information flow and most of the needed basic information comes from the building information model. Collaboration between project participants is needed, if 5D BIM is wanted to be used in the most efficient way. The same data is used throughout the project, so sequential phases should be taken into consideration when creating new information or structuring it. Designers must have clear instructions about the use of information fields or additional applications should be used for standardization.

The 5D BIM application was considered versatile, but because of this, the usage was complicated. The literature research presented that there was no BIM software that could perform all the functions BIM could enable. The application used in this research could combine cost estimation and schedule planning under one application, but some of the modules or combination of modules were not as good as other applications available. The application made it possible to automatize Element Planning and procurement to some extent.

7.4 Recommendations

The usage of the Talo 2000 project and production classifications together is recommended. It is easier to track the subcontracting costs when there is a separate structure for work packages. There was no additional work operating with two classifications and the allocation of classification could be automatized in the 5D BIM application.

The information fields provided by the design models should be standardized. This would help to automatize the cost calculation process and could create more reliable information. The case company should create clear design instructions and use additional applications for alteration of the models, when needed.

Earned Value Management should be taken to use in the case company while implementing the 5D BIM application. The application enables an easy way to report the information needed for EVM and gives the management simple key figures to follow.

7.5 Suggestions for future research

The usage of 5D BIM and design options could be researched to present how practical it is to use 5D BIM for estimating the costs of different design options. It could be researched, if cost estimation could be automatized and the possibility of creating intelligent functions for comparing design options, such as cast-in-place or prefabricated units. An extensive study of the cost management of the design phase should be made.

The information flow from development to execution should be researched. This study was limited by using light partition walls and detailed design information, but a more extensive study could be made to presents the critical points of decisions making and how they reflect in the execution phase. Structuring of this information should be researched by using the available classifications.

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APPENDIX A: TALO 2000 PROJECT CLASSIFICATION

1 Building elements

11 Site elements
12 Building elements
13 Internal space elements (infills)

2 Services elements

21 Plumbing elements
22 Air conditioning elements
23 Electrical elements
24 Data transfer elements
25 Mechanical elements

3 Project-related tasks

31 Project management tasks
32 Design tasks
33 Construction management tasks
34 Site tasks

4 Property management tasks

41 Site tasks
42 Financing and marketing

5 User tasks

51 Space equipment
52 Maintenance of operation

6 Project provisions

61 Document and price level changes
62 Other provisions

APPENDIX B: "FIRA 2000": TALO 2000 PRODUCTION CLASSIFICATION WITH THE CASE COMPANY'S MODIFICATIONS

0 Design and research

0.1 Architectural design
0.2 Structural design
0.3 Prefabricated units design
0.4 HPAC and automation design
0.5 Electrical design
0.6 Geographical design
0.7 Fire technical design
0.8 Acoustic design
0.9 Landscape design

1 Demolition

1.1 Demolition of building elements
1.2 Demolition of hazardous substances
1.3 Transferring of buildings

2 Groundwork

2.1 Pre-construction work (compaction, stabilization, stabilizing berms)
2.2 Groundwork
2.3 Rock engineering
2.4 Foundation work (pile driving, sheeting)
2.5 Dewatering (onsite controlling of groundwater)

3 Integrated development

3.1 Rock coating
3.2 Wood coating
3.3 Asphalt work
3.4 Special coating
3.5 Landscaping
3.6 Area equipment

4 Concrete work

4.1 Concrete work
4.2 Precast concrete elements
4.3 Special concrete work
4.4 Topping work (floor work)
4.5 Ribbed reinforcement bars and mesh
4.6 Concrete deliveries

5 Masonry

5.1 Masonry
5.2 Not in use
5.3 Pantile work

5.4 Tile and waterproofing

6 Metal work

6.1 Metal structure work (columns and beams)
6.2 Metal prefabricated unit work (metal plate sandwich units)
6.3 Prefabricated metal products
6.4 Complementary metal work (railings, shelters…)
6.5 Metal plate work
6.6 Box unit works (bathrooms)

7 Carpenter and board work

7.1 Frame construction (roof, exterior walls)
7.2 Prefabricated timber unit work (trusses, beams)
7.3 Prefabricated wood-based products work (windows, balcony doors)
7.4 Board work (partition walls, suspended ceilings)
7.5 Wooden surfaces (not including parquets or laminates)

8 Glass work

8.1 Glazing
8.2 Special glazing
8.3 Balcony glazing

9 Insulation

9.1 Sound insulation
9.2 Damp proofing (bitumen works)
9.3 Fire compartmentation
9.4 Jointing

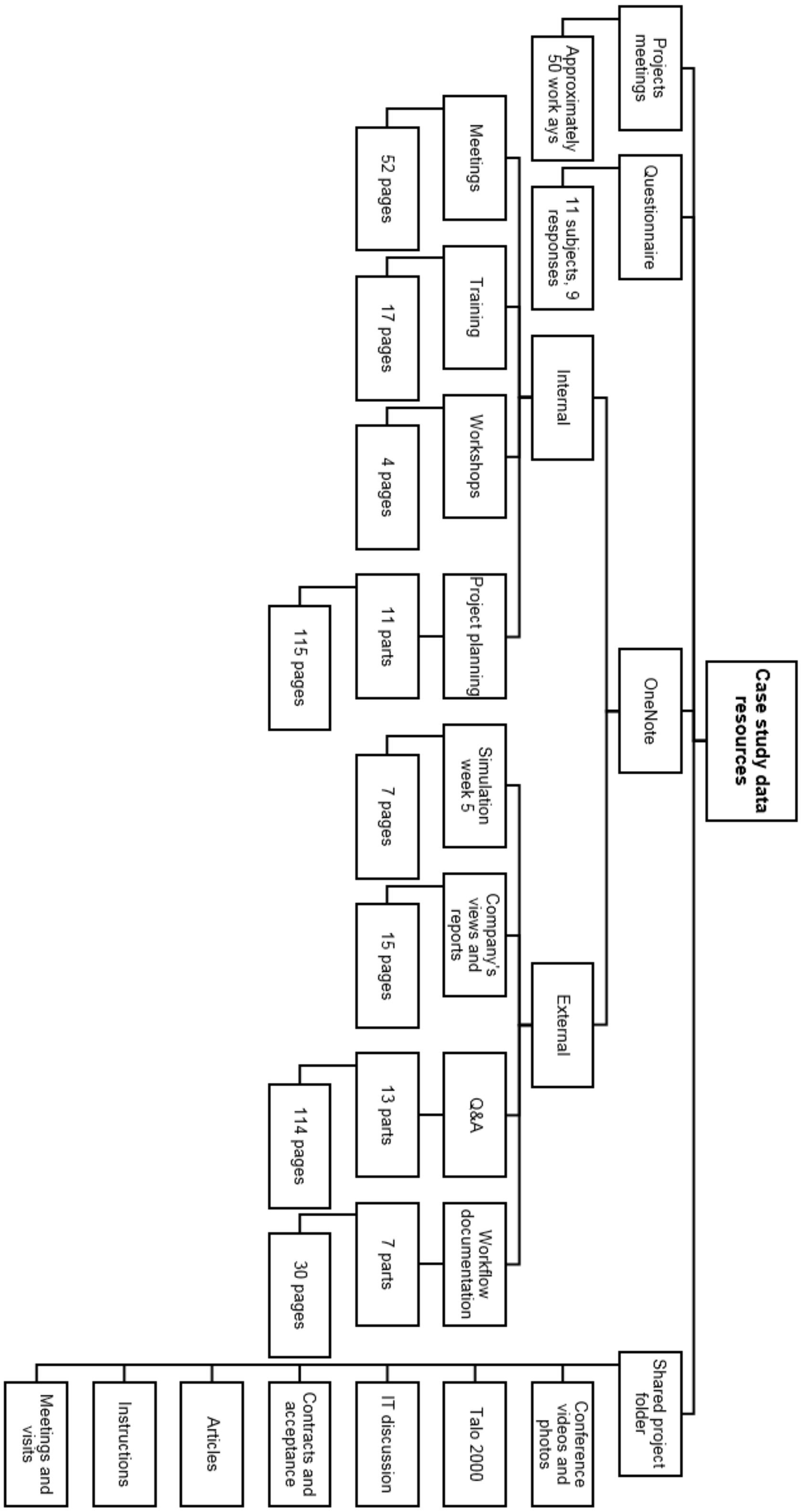
10 Surface work

10.1 Plastering
10.2 Puttying
10.3 Painting and wallpapering
10.4 Carpet works
10.5 Composition flooring
10.6 Other surface construction
10.7 Molding

11 Equipment

11.1 Ironmongery work and locking
11.2 Internal fixtures
11.3 Equipment installation
11.4 Standard appliances

APPENDIX C: CASE STUDY DATA SOURCES



APPENDIX D: DEMONSTRATION DATA SOURCES